PB-241 990

ENERGY CONSUMPTION

THE PRIMARY METALS AND PETROLEUM INDUSTRIES

DOW CHEMICAL COMPANY

PREPARED FOR
NATIONAL ENVIRONMENTAL RESEARCH CENTER

APRIL 1975

DISTRIBUTED BY:
NTIS
National Technical Information Service
U. S. DEPARTMENT OF COMMERCE

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. PB 241 990
EPA-650/2-75-032-b		

4. TITLE AND SUBTITLE	5. REPORT DATE
Energy Consumption: The Primary Metals and Petroleum Industries	April 1975
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
John T. Reding and Burchard P. Shepherd	
9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT NO.
Dow Chemical, U.S.A. Texas Division Freeport, Texas 77541	1AB013; ROAP 21ADE-010
	11. CONTRACT/GRANT NO.
	68-02-1329, Task 5
12. SPONSORING AGENCY NAME AND ADDRESS	13. TYPE OF REPORT AND PERIOD COVERED
EPA, Office of Research and Development NERC-RTP, Control Systems Laboratory Research Triangle Park, NC 27711	Final Task; 8/74-3/75
	14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

16. ABSTRACT The report gives results of a study of energy consumption in the primary metals and petroleum industries. It analyzes energy-intensive steps or operations for commonly used manufacturing processes. Results of the analyses are in the form of energy consumption block diagrams, energy-intensive equipment schematic diagrams, and tables that indicate the causes of energy losses, as well as possible conservation approaches. The most common energy-intensive operations in these industries are: (primary metals) -- furnace operation and electrolysis; and (petroleum) -- furnace operation and distillation. Energy losses in these operations could be reduced by: design, operation, and process modification; better insulation and maintenance; process integration; waste utilization; and research and development.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Energy	Distillation	Primary Metals Industry	13H
Consumption	Insulation		
Metal Industry	Maintenance		11F
Petroleum Industry	Wastes		
Conservation	Processing		
Furnaces	Research		13A
Electrolysis	Design		07D

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES
Unlimited	Unclassified	59
	20. SECURITY CLASS *(This page)*	22. PRICE
	Unclassified	$4.25/2.25

EPA Form 2220-1 (9-73)

EPA-650/2-75-032-b

ENERGY CONSUMPTION:

THE PRIMARY METALS

AND PETROLEUM INDUSTRIES

by

John T. Reding and Burchard P. Shepherd

Dow Chemical, U. S. A.
Texas Division
Freeport, Texas 77541

Contract No. 68-02-1329, Task 5
Program Element No. 1AB013
ROAP No. 21ADE-010

EPA Project Officer: Irvin A. Jefcoat

Control Systems Laboratory
National Environmental Research Center
Research Triangle Park, North Carolina 27711

Prepared for

U. S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF RESEARCH AND DEVELOPMENT
WASHINGTON, D. C. 20460

April 1975

EPA REVIEW NOTICE

This report has been reviewed by the National Environmental Research Center - Research Triangle Park, Office of Research and Development, EPA, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into series. These broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and maximum interface in related fields. These series are:

1. ENVIRONMENTAL HEALTH EFFECTS RESEARCH
2. ENVIRONMENTAL PROTECTION TECHNOLOGY
3. ECOLOGICAL RESEARCH
4. ENVIRONMENTAL MONITORING
5. SOCIOECONOMIC ENVIRONMENTAL STUDIES
6. SCIENTIFIC AND TECHNICAL ASSESSMENT REPORTS
9. MISCELLANEOUS

This report has been assigned to the ENVIRONMENTAL PROTECTION TECHNOLOGY series. This series describes research performed to develop and demonstrate instrumentation, equipment and methodology to repair or prevent environmental degradation from point and non-point sources of pollution. This work provides the new or improved technology required for the control and treatment of pollution sources to meet environmental quality standards.

This document is available to the public for sale through the National Technical Information Service, Springfield, Virginia 22161.

Publication No. EPA-650/2-75-032-b

CONTENTS

		Page
EPA Review Notice		ii
List of Figures		iv
List of Tables		vi
Sections		
I	Conclusions	1
II	Recommendations	2
III	Introduction	3
IV	Energy Consumption within the Primary Metals and Petroleum Industries	5
	A. Steel by the Basic Oxygen Process	5
	B. Aluminum by the Bayer-Hall Process	18
	C. Petroleum Refining	29
	D. Summary of Energy Losses and Recommended Conservation Approaches	44
V	Bibliography	49
VI	Glossary of Abbreviations	51
VII	Appendix	52

FIGURES

No.		Page
1	Steel Energy Consumption Diagram	6
2	Steel Energy Intensive Equipment Diagram --Coke Oven	10
3	Steel Energy Intensive Equipment Diagram --Sinter Operation	11
4	Steel Energy Intensive Equipment Diagram --Pelletizing	12
5	Steel Energy Intensive Equipment Diagram --Blast Furnace and Blast Stoves	14
6	Steel Energy Intensive Equipment Diagram --Steelmaking (Basic Oxygen Furnace)	15
7	Steel Energy Intensive Equipment Diagram --Steelmaking (Open Hearth Furnace)	16
8	Steel Energy Intensive Equipment Diagram --Steelmaking (Electric Furnace)	17
9	Steel Energy Intensive Equipment Diagram --Soaking Pit	19
10	Steel Energy Intensive Equipment Diagram --Reheating Furnace	20
11	Steel Energy Intensive Equipment Diagram --Annealing Ovens	21
12	Aluminum Energy Consumption Diagram	25
13	Aluminum Energy Intensive Equipment Diagram --Steam Digestion of Bauxite and Evaporation of Water from Caustic	27
14	Aluminum Energy Intensive Equipment Diagram --Rotary Kiln	28
15	Aluminum Energy Intensive Equipment Diagram --Electrolysis Cell	30
16	Aluminum Energy Intensive Equipment Diagram --Melting Furnace	31

FIGURES (continued)

No.		Page
17	Petroleum Refining Energy Consumption Diagram	35
18	Petroleum Refining Energy Intensive Equipment Diagram--Crude Distillation	37
19	Petroleum Refining Energy Intensive Equipment Diagram--Distillate Hydrodesulfurization	38
20	Petroleum Refining Energy Intensive Equipment Diagram--Catalytic Reforming	40
21	Petroleum Refining Energy Intensive Equipment Diagram--Fluid Catalytic Cracking	41
22	Petroleum Refining Energy Intensive Equipment Diagram--HF Alkylation	42
23	Petroleum Refining Energy Intensive Equipment Diagram--Aromatics Extraction	43
24	Petroleum Refining Energy Intensive Equipment Diagram--Coking	45

TABLES

No.		Page
1	Steel Energy Conservation Approaches	22
2	Aluminum Energy Conservation Approaches	32
3	Petroleum Refining Energy Conservation Approaches	46
4	Summary of Energy Losses and Recommended Conservation Approaches	47

SECTION I

CONCLUSIONS

Most of the energy consumption within the primary metals industry is concentrated in a relatively few operations. Furnace combustion is the principal operation in the steel manufacturing process. Electrolysis is the principal operation in the aluminum manufacturing process. Most of the energy consumption within the petroleum industry occurs in furnace combustion and distillation operations. Losses in these operations can be decreased by employing conservation approaches. These include:

- Design modifications to increase waste heat recovery from furnaces.
- Design modifications to recover energy from high pressure streams in parts of the petroleum refining process.
- Design modifications to allow lower energy input into distillation columns.
- Proper maintenance practices, especially with regard to heat exchange surfaces and insulation.
- Operation modifications to avoid losses in electrolytic cells and distillation columns.
- Greater use of insulation to limit heat losses.
- Research and development to develop processes with increased yields.
- Waste utilization by more recycle of scrap steel and aluminum.
- Waste utilization to prevent the loss of the fuel value of waste streams.

SECTION II

RECOMMENDATIONS

The energy conservation approaches suggested in this report could be further defined and specified in more detail. Unanswered questions which should be considered include:

- The economic feasibility of the conservation approaches.
- The difficulty of implementing the approaches.

SECTION III

INTRODUCTION

Purpose

The purpose of the total task is to provide a breakdown of energy consumption within the six primary industrial categories--primary metals, chemicals, petroleum, food, paper, and stone, clay, glass, concrete. The purpose of the portion of the total task covered by this report is to provide a breakdown of energy consumption within the primary metals and petroleum industries only. This breakdown can give direction to subsequent conservation efforts.

Scope

This report analyzes high energy consumption operations within the primary metals industry (SIC 33) and the petroleum industry (SIC 29). The principal pieces of energy-intensive equipment used in these operations are identified. Finally, the causes of energy losses in these operations, the approximate magnitude of the losses, and possible approaches to decrease these losses are indicated.

General Background

The National Academy of Engineering has been commissioned by the Environmental Protection Agency to conduct a comprehensive assessment of the current status and future prospects of sulfur oxides control methods and strategies. The agreement between the Environmental Protection Agency and the National Academy of Engineering states explicitly that special data collection projects may be required to provide the National Academy of Engineering panel with the background necessary for viewing all aspects of the problem in perspective. This report is one segment of the data collection project associated with the National Academy of Engineering assessment.

One method of limiting the amount of SO_x emissions arising from energy conversion is simply to decrease fuel use through energy conservation. In the year 1968, it has been reported that 41.2 percent of the total energy consumption in the United States was in the industrial sector. More specifically, 28 percent of the national energy consumption was in the six industrial categories encompassed by this total task. Conservation efforts directed toward industries in these six categories should obtain the greatest impact.

General Approach

The processes for manufacturing steel and aluminum were reviewed. Approximately 85 percent of the energy consumption within the primary metals category occurs in the manufacturing processes for these two metals. In addition, the process for refining crude oil was reviewed.

Energy consumption block diagrams were drawn for each process. These diagrams indicate the operations within the processes where large amounts of energy are used. These energy-intensive operations have been further analyzed. Schematic diagrams show the physical and operational appearance of the energy-consuming equipment. Causes of energy losses in the energy-intensive operations, the approximate magnitude of the losses, and possible conservation approaches have been determined.

SECTION IV

ENERGY CONSUMPTION WITHIN THE PRIMARY METALS AND PETROLEUM INDUSTRIES

Several observations need to be made concerning the analyses of energy consumption in the steel, aluminum, and petroleum refining processes.

- The type of energy used in each energy-intensive operation is included on the process block diagrams. Different types of energy are not equivalent. Approximately 3 Btu's of fuel energy are required to generate 1 Btu of electrical energy. Approximately 1.1 to 1.3 Btu's of fuel energy are required to generate 1 Btu of steam energy.

- Energy values for the steel and aluminum processes are always expressed in terms of energy per unit weight of product. Energy values for the petroleum refining process are expressed in terms of energy per unit weight of crude oil processed.

- The tables showing energy conservation approaches give estimates of losses in each operation of the process and in the overall process. The losses listed in each operation are additive. The losses listed in the overall process often overlap with losses within operations and are not additive.

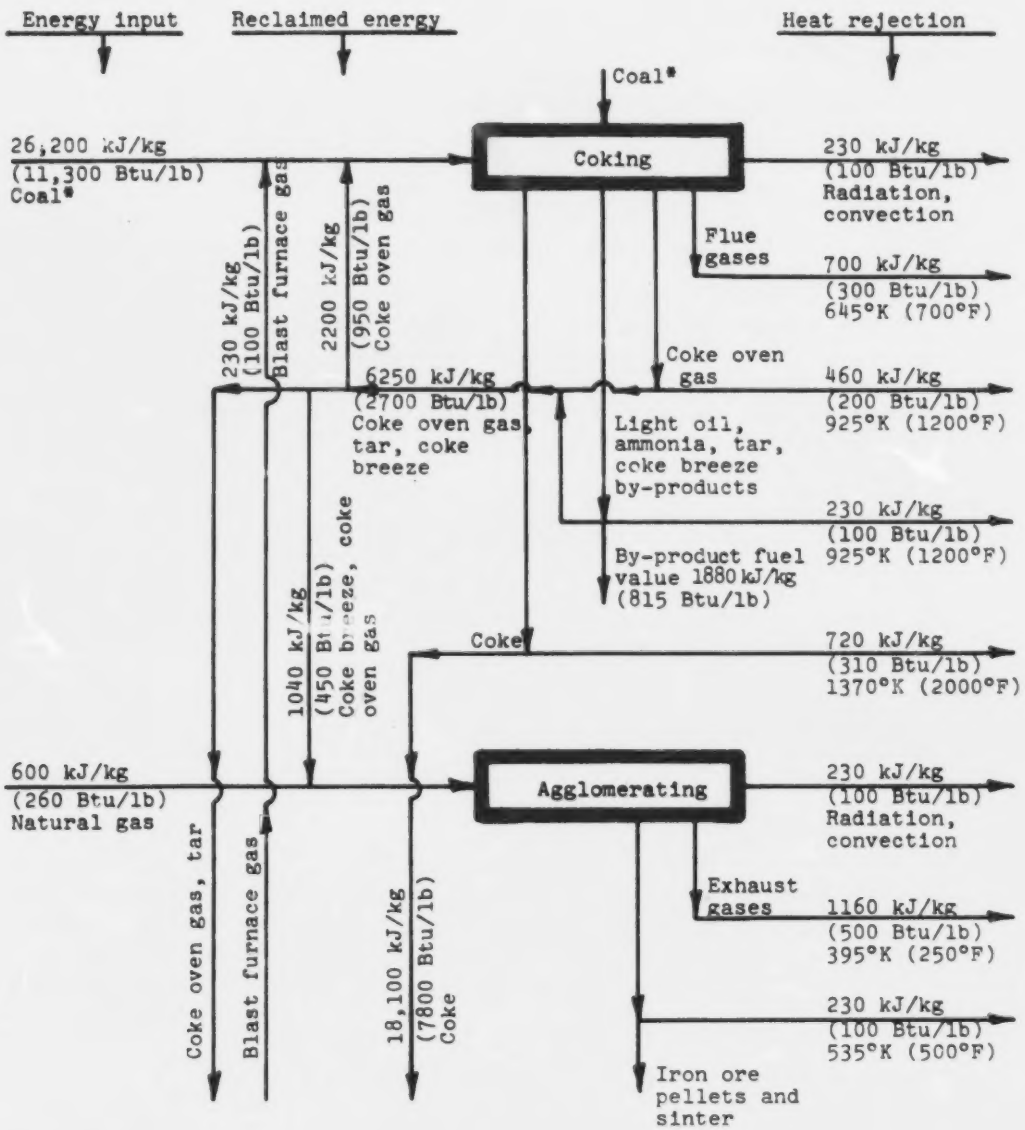
- The values for energy input and losses are derived from a variety of sources as listed in the bibliography. The values are typical for published technology. New plants may already use conservation approaches recommended in this report and, thereby, use less energy than indicated in the figures.

- Energy conservation approaches are listed in the tables. In many cases a more specific explanation of the recommended energy conservation approach is listed along with the approach. An explanation of the conservation approaches is included in the appendix for those instances where the meaning of the term may be vague.

A. Steel by the Basic Oxygen Process

Figure 1 shows the primary steps in the steel manufacturing process using the basic oxygen furnace. The major energy consumption operations are coking of coal; agglomerating of

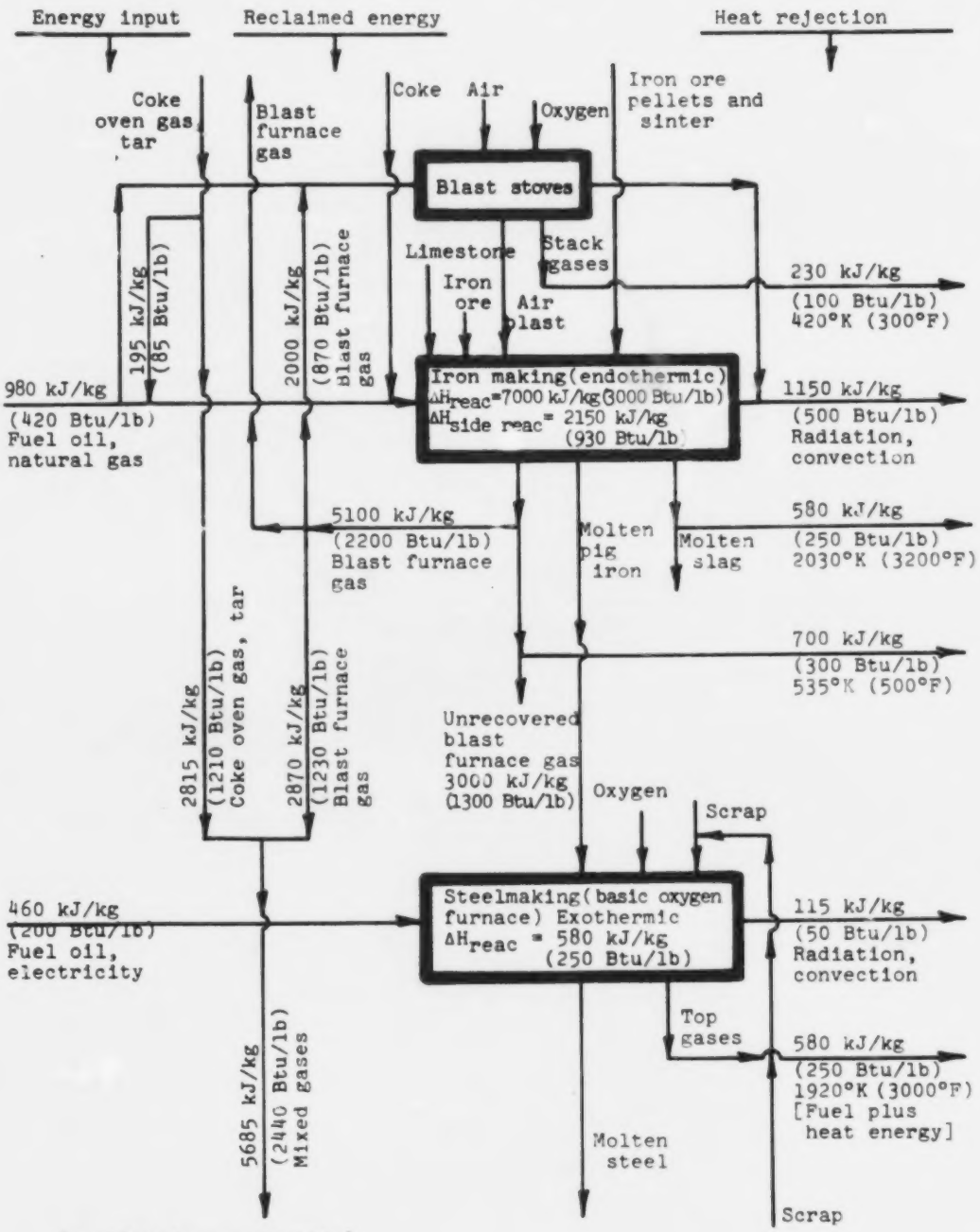
Figure 1. Steel energy consumption diagram
[1972 USA shipments: 83.5 x 10^9 kg (184 x 10^9 lb)]
[1972 energy consumption (primarily coal and natural gas): 110,000 MW (3300 x 10^{12} Btu)]



* Coal is feed and energy source in this operation.

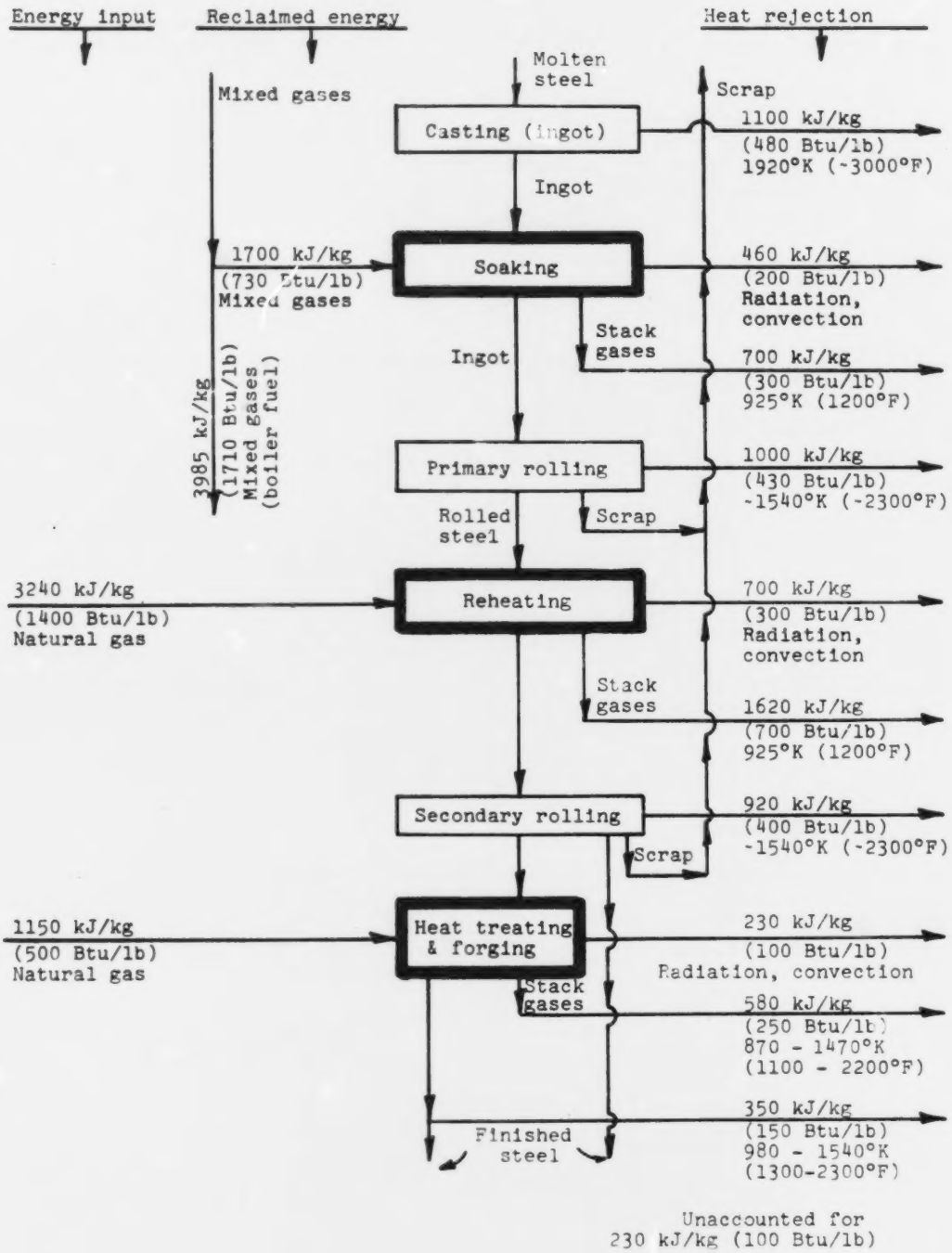
(continued on next page)

Figure 1 (Continued).



(continued on next page)

Figure 1 (Continued)



iron ore; ironmaking; steelmaking; soaking of ingots; reheating of blooms, billets, and slabs; and heat-treating or forging. These operations account for more than 80 percent of the total energy consumption in the manufacture of steel.

Energy consumption in the steel manufacturing process is highly dependent on the ratio of scrap-to-blast-furnace iron that is fed to the steelmaking furnace. The energy values used in this report are based on a scrap-to-pig iron feed ratio of 1:2. This is approximately the average of the overall steel industry.

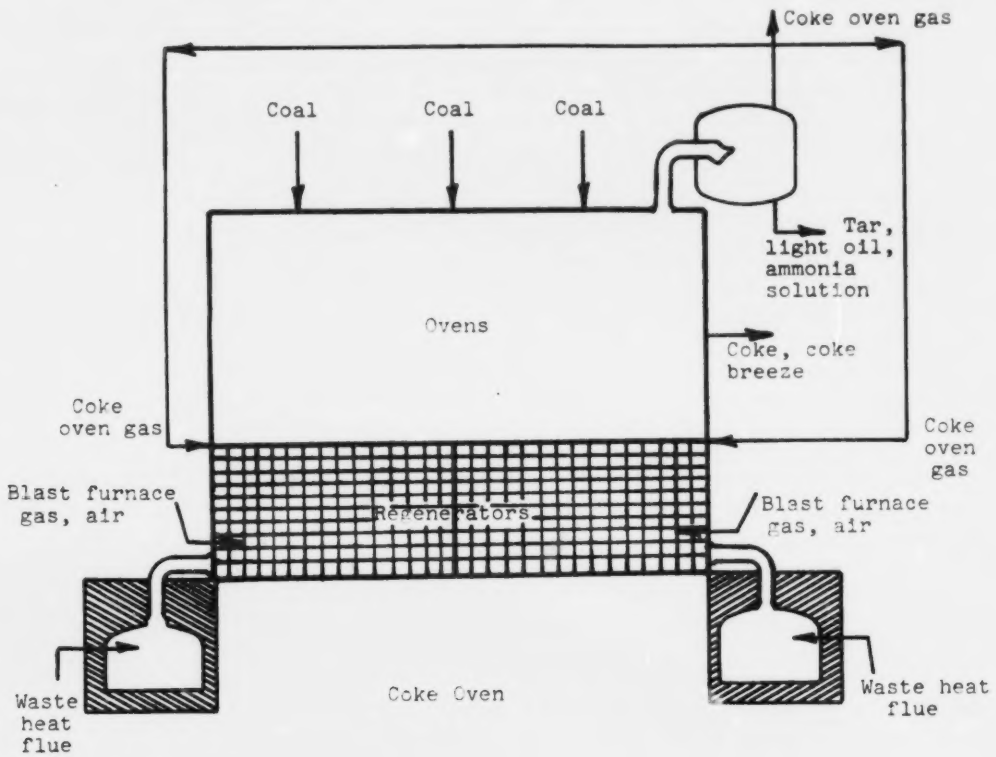
Figure 2 shows the coking operation. Coal is distilled at approximately 1370°K (2000°F) using the combustion of coke oven gas and blast furnace gas as the heat source. The coke oven is a rather complicated piece of equipment. Coal is located in narrow slots typically 40 feet long by 20 feet high by 18 inches wide. Hot combustion gases pass between slots containing coal, down through brick checkerwork, and then out waste heat flues. Combustion air is preheated by passing through previously heated brick checkerwork. Flow of combustion gases is reversed periodically so that each half of the brick checkerwork (regenerators) is being heated half the time and cooled half the time. Products from the coke oven include coke, coke oven gas, tar, light oil, ammonia solution, and coke breeze (small pieces of coke which pass through 1/2-inch screen). The coke oven gas, coke breeze, and part of the tar are used as fuel in other portions of the steel manufacturing process.

Figures 3 and 4 show two agglomerating operations that are commonly used to improve iron ore permeability and improve gas-solid contact in the blast furnace. Agglomeration also decreases the amount of fine material that is blown out of the blast furnace. The agglomerating operations are sintering and pelletizing.

Figure 3 shows that the sintering operation occurs on a traveling grate that conveys a bed of ore fines, limestone fines, and coke breeze. The bed (coke breeze) is ignited by gas burners and, as the mixture moves along the grate, air is pulled down through the mixture to keep the breeze burning. The heat sinters the mixture at 1640°K (2500°F) into pea- to baseball-size lumps. Approximately one-third of the iron ore burden in a typical blast furnace is sintered.

Figure 4 shows that the pelletizing operation also occurs on a traveling grate. Pellets are formed from iron ore, bentonite, and moisture. The pellets are coated with coal

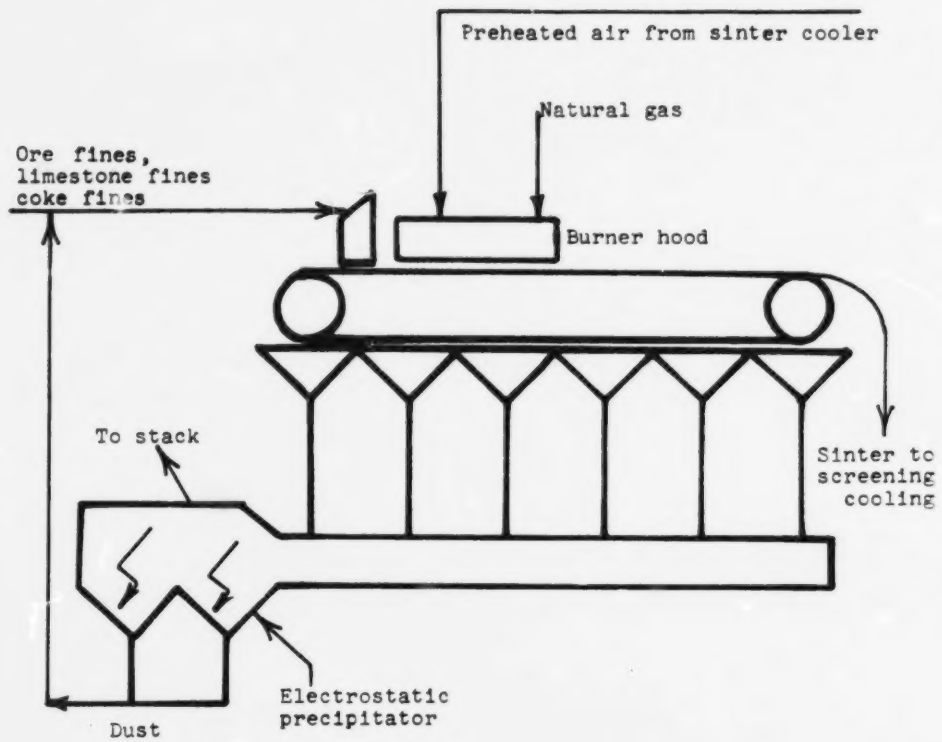
Figure 2. Steel energy intensive equipment diagra - coke oven
[Rejected heat: Radiation - 230 kJ/kg (100 Btu/lb)
Flue gases - 700 kJ/kg (300 Btu/lb) at 645°K (700°F)
Coke oven gas - 460 kJ/kg (200 Btu/lb) at 925°K (1200°F)
Tar, light oil, ammonia water stream - 230 kJ/kg (100 Btu/lb) at 925°K (1200°F)
Coke - 720 kJ/kg (310 Btu/lb) at 1370°K (2000°F)]



Energy input		
coal	26,200 kJ/kg	(11,300 Btu/lb)
gases	2,440 kJ/kg	(1,050 Btu/lb)
Energy output		
coke	18,100 kJ/kg	(7,800 Btu/lb)
coke oven gas	5,560 kJ/kg	(2,400 Btu/lb)
tar	1,270 kJ/kg	(550 Btu/lb)
light oils	325 kJ/kg	(140 Btu/lb)
coke breeze	970 kJ/kg	(420 Btu/lb)
losses	2,440 kJ/kg	(1,050 Btu/lb)

Note: All energy is expressed in terms of energy per unit weight of finished steel.

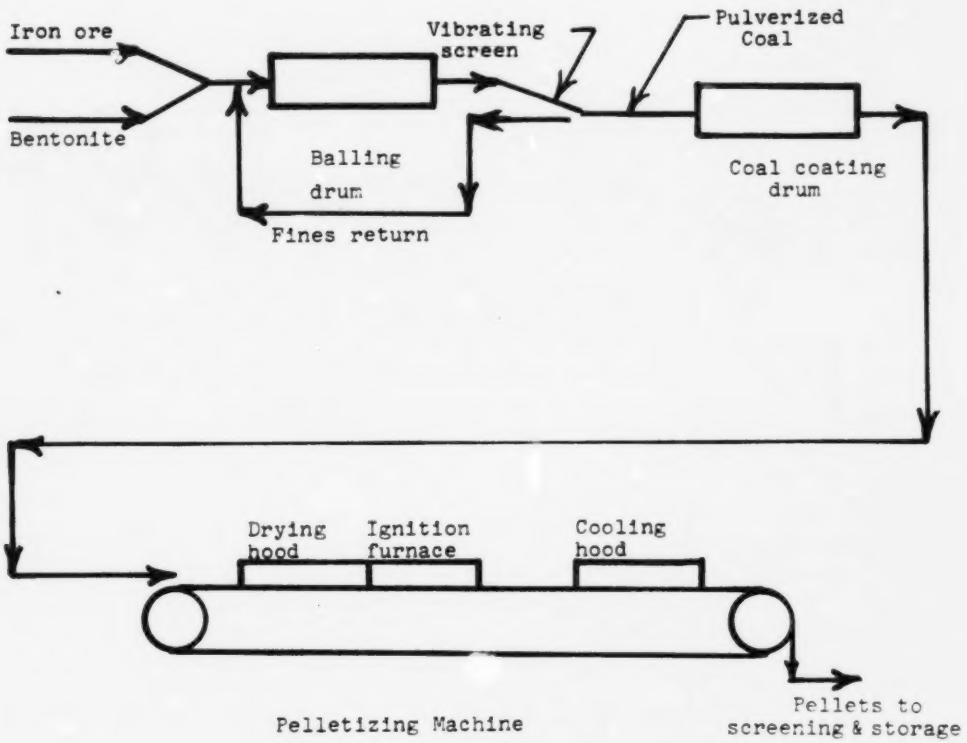
Figure 3. Steel energy intensive equipment diagram - sinter operation
[Rejected heat: Radiation - 230 kJ/kg (100 Btu/lb)
Exhaust gases - 1160 kJ/kg (500 Btu/lb) at 395°K (250°F)
Hot sinter or pellets - 230 kJ/kg (100 Btu/lb) at 535°K (500°F)]*



* Rejected heat quantities are totals for sintering and pelletizing operations.

Note: All energy is expressed in terms of energy per unit weight of finished steel

Figure 4. Steel energy intensive equipment diagram - pelletizing
[Rejected heat: Radiation - 230 kJ/kg (100 Btu/lb)
Exhaust gases - 1160 kJ/kg (500 Btu/lb) at 395°K (250°F)
Hot sinter or pellets - 230 kJ/kg (100 Btu/lb) at 535°K (500°F)]*



* Rejected heat quantities are totals for sintering and pelletizing operations.

Note: All energy is expressed in terms of energy per unit weight of finished steel.

which is ignited on the traveling grate. Recuperated hot air from the cooling hood is used to dry and preheat the pellets. Natural gas is used to ignite the pulverized coal or coke breeze fuel. Some heat is sometimes obtained from the oxidation of magnetite to hematite. The pelletizing operation occurs at 1370-1590°K (2000-2400°F). Approximately 50 percent of the iron ore burden in a typical blast furnace is pelletized.

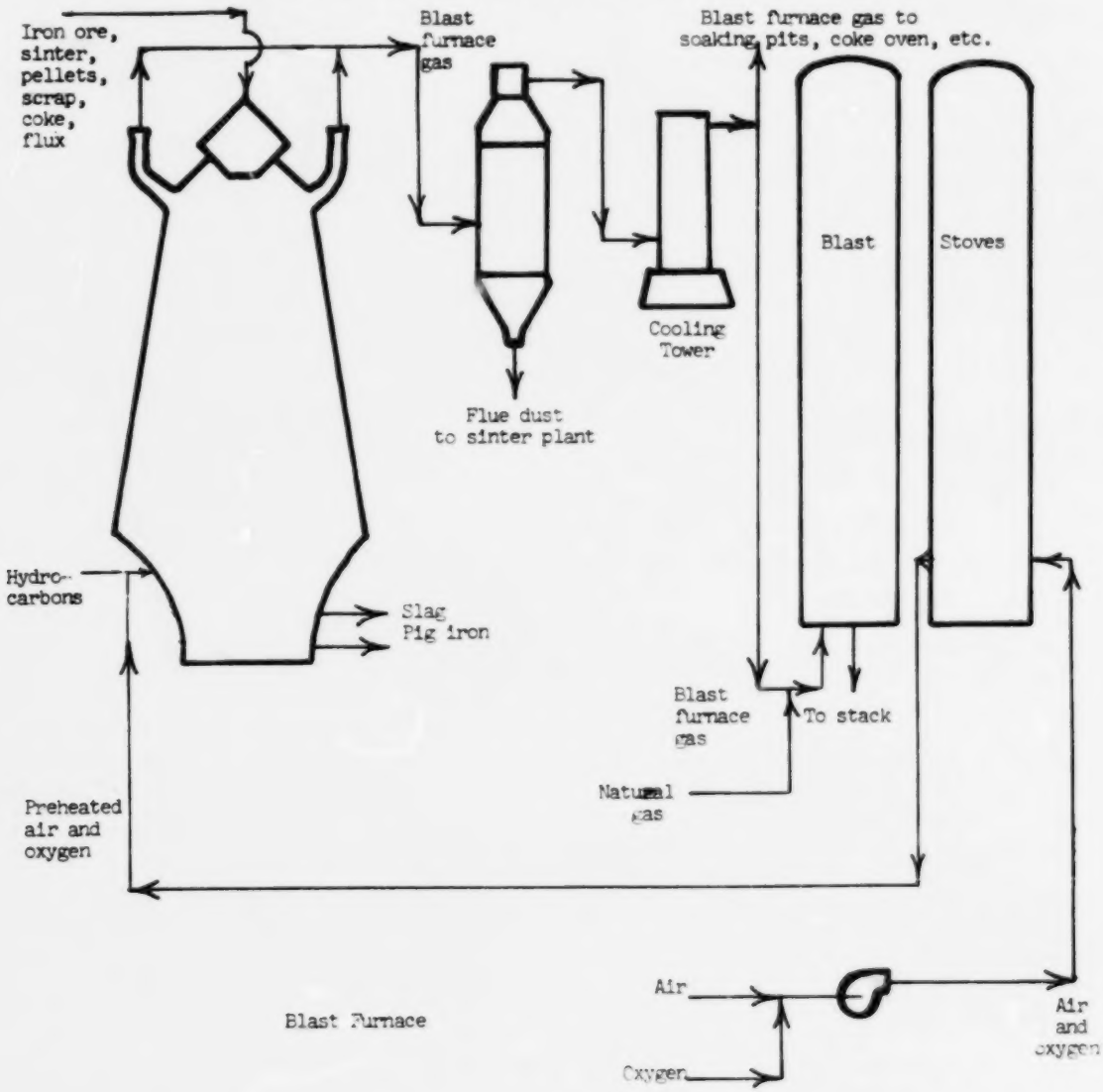
Figure 5 shows the ironmaking portion of the steel manufacturing process. The reduction of iron ore to iron takes place in the blast furnace. The reducing agent is coke which not only reduces the iron ore but also provides heat to melt the iron. Additional heat is also provided by the "hot blast" which is a mixture of air and oxygen that has been heated in the blast stoves. The fuel for the blast stoves is blast furnace gas plus natural gas. Some hydrocarbon fuels are also generally injected into the blast furnace. The temperature in the lower part of the blast furnace is 1750°K (2700°F). The blast furnace gas coming off the top of the furnace is used as a fuel throughout the steel process.

Figure 6 shows the steelmaking operation using the basic oxygen furnace. Pig iron from the blast furnace generally contains excessive amounts of carbon, silicon, manganese, and phosphorus. These impurities are quickly oxidized by oxygen which is blown onto the molten metal. These oxidation reactions liberate heat so that very little additional heating is needed to keep the metal molten.

Figure 7 shows the steelmaking operation using the open hearth furnace. Air for combustion passes through brick checkerwork regenerators in one direction for 15 to 20 minutes and then is directed in the opposite direction. The air provides oxygen to oxidize impurities in the steel and to burn fuel for heat. The combustion gases pass through the brick checkerwork regenerators and then to boilers. The open hearth furnace is declining in importance because of its slowness. It also requires more energy than the now dominant basic oxygen furnace. The use of an oxygen lance increases the speed of this operation and also decreases energy consumption. The decrease in energy consumption is due primarily to a decrease in the amount of heat-absorbing nitrogen which passes through the system.

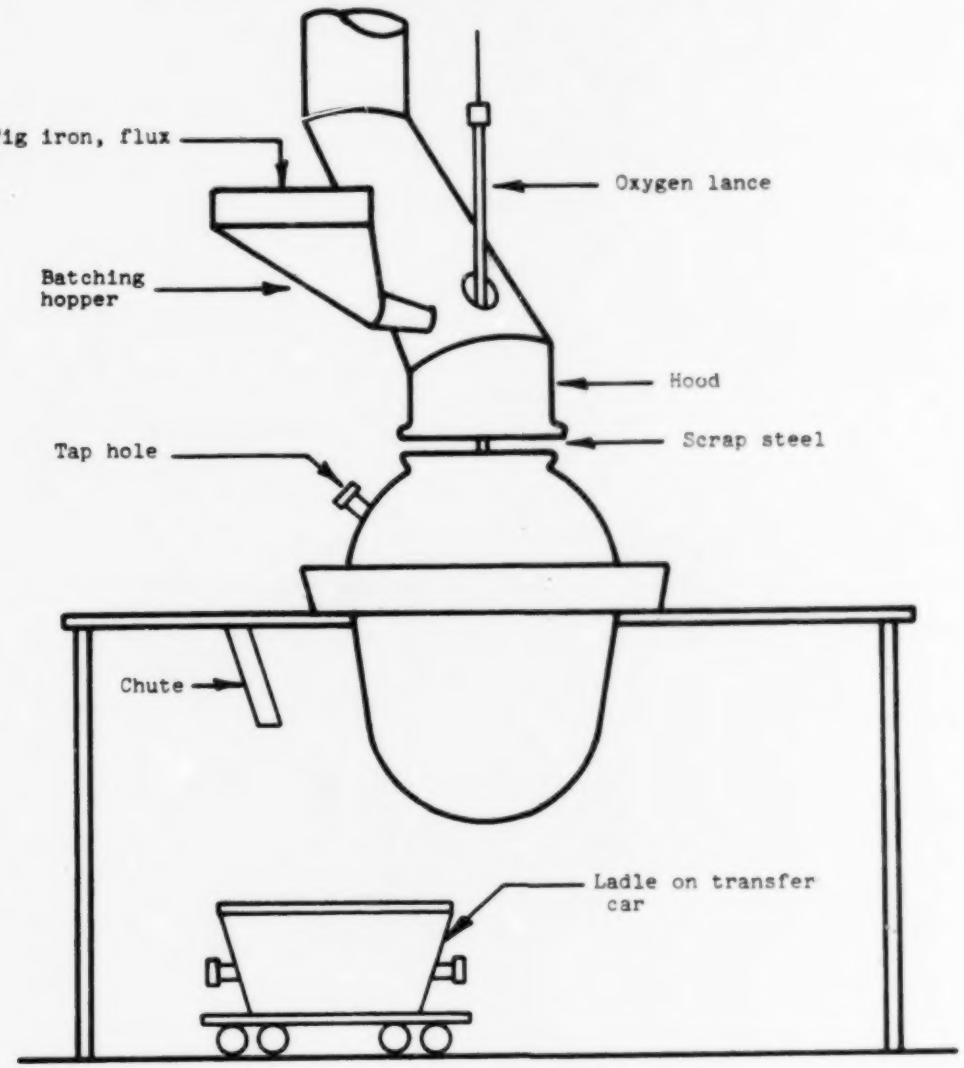
Figure 8 shows the steelmaking operation using a direct-arc electric furnace. Electricity is used to generate heat to melt scrap steel. Preheating of the charge can be used to reduce energy requirements in melting scrap. Oxygen lancing speeds oxidation of pig iron and results in energy savings. This method of producing steel is increasing in importance.

Figure 5. Steel energy intensive equipment diagram - blast furnace and blast stoves
[Rejected heat: Radiation, other - 1150 kJ/kg (500 Btu/lb)
Sensible heat in blast furnace gas - 700 kJ/kg (300 Btu/lb) at 535°K (500°F)
Stack gas from blast stoves - 230 kJ/kg (100 Btu/lb) at 420°K (300°F)
Molten slag - 580 kJ/kg (250 Btu/lb) at 2030°K (3200°F)
Molten iron transfer - 70 kJ/kg (30 Btu/lb) at 2030°K (3200°F)]
[Lost fuel: Blast furnace gas - 3000 kJ/kg (1300 Btu/lb)]



Note: All energy is expressed in terms of energy per unit weight of finished steel.

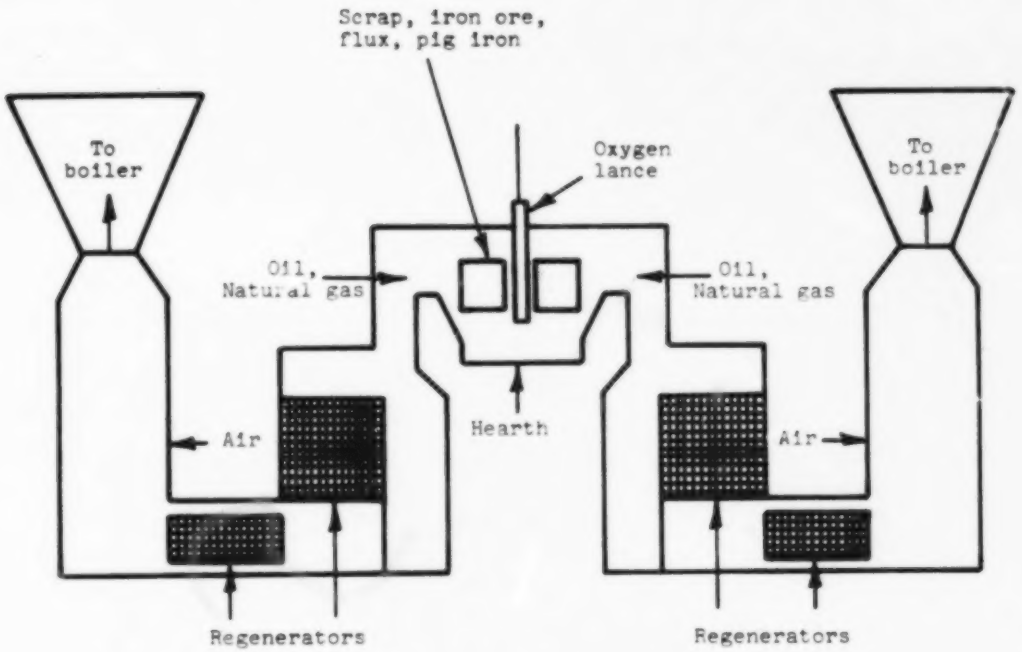
Figure 6. Steel energy intensive equipment diagram - steel making (basic oxygen furnace)
[Rejected heat: Radiation - 115 kJ/kg (50 Btu/lb)
Top gases (fuel value plus sensible heat)- 580 kJ/kg (250 Btu/lb) at 1920°K (3000°F)]



Basic Oxygen Furnace

Note: All energy is expressed in terms of energy per unit weight of finished steel.

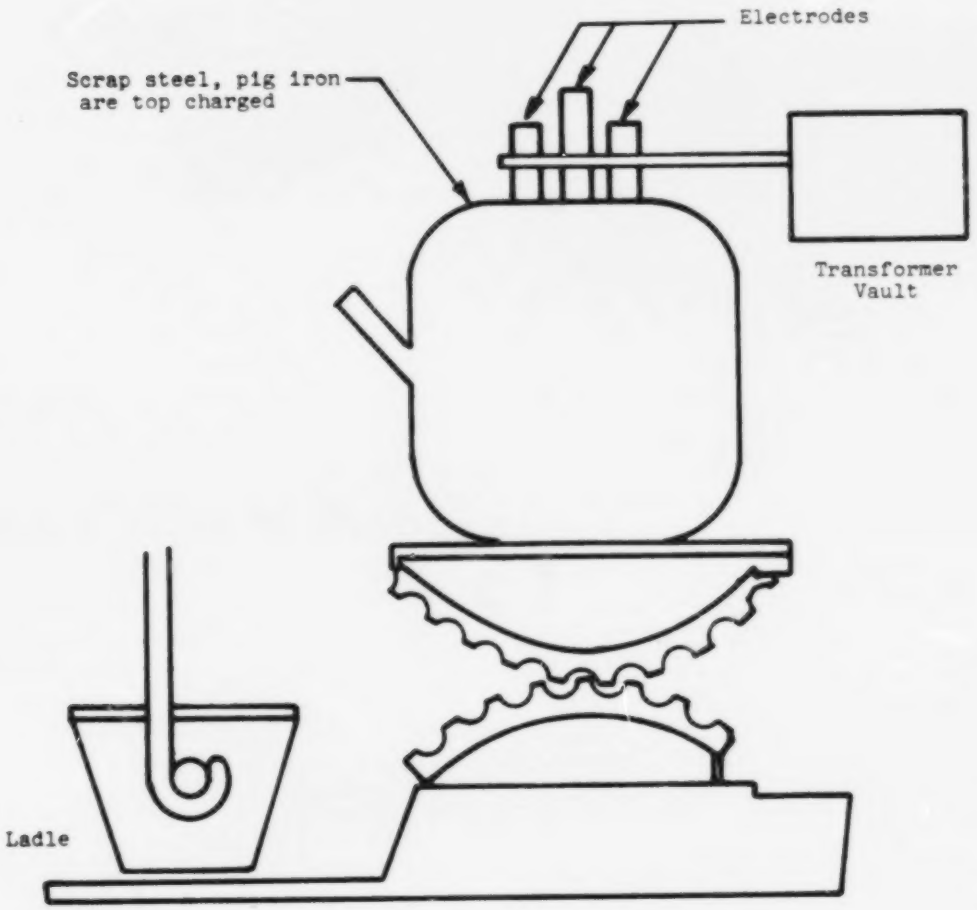
Figure 7. Steel energy intensive equipment diagram - steelmaking (open hearth furnace with oxygen injection)
[Rejected heat: Radiation - 1350 kJ/kg (580 Btu/lb)
Stack gas heat - 840 kJ/kg (360 Btu/lb) at 480°K (400°F)]
[Heat used for steam generation - 700 kJ/kg (300 Btu/lb)]



Open hearth furnace

Note: All energy is expressed in terms of energy per unit weight of finished steel produced using the open hearth furnace.

Figure 8. Steel energy intensive equipment diagram - steelmaking (electric furnace)
[Rejected heat: Radiation, conduction - 700 kJ/kg (300 Btu/lb)]



Electric-arc furnace

Note: All energy is expressed in terms of energy per unit weight of finished steel produced using an electric furnace.

Figure 9 shows the soaking pit operation using a two-way gas-fired soaking pit. Often coke oven gas and blast furnace gas are used to heat solidified ingots to approximately 1600°K so that they can be rolled into blooms, billets, and slabs. Recuperators allow some of the heat from combustion gases to be retained in the furnace by transferring this heat to incoming combustion air.

Figure 10 shows the reheating operation using a five-burner, countercurrent fired, pusher-type, continuously reheating furnace. Natural gas can be used as fuel in this operation which heats slabs, blooms, and billets to approximately 1530°K so that they can be further rolled or milled into finished products. Recuperators allow some of the heat from combustion gases to be retained in the furnace by transferring this heat to incoming combustion air.

Figure 11 shows a radiant-type annealing furnace. Approximately 25 percent of finished steel products are given an annealing treatment at 920-1090°K (1200-1500°F) to relieve stresses in the steel. Another 15 percent is processed at 1450-1510°K (2150-2250°F) in forging furnaces. Natural gas is often used to provide energy for these operations.

Table 1 shows the causes of energy losses in the operations of the steel process. It also gives an estimate of the magnitude of the losses and some possible energy conservation approaches.

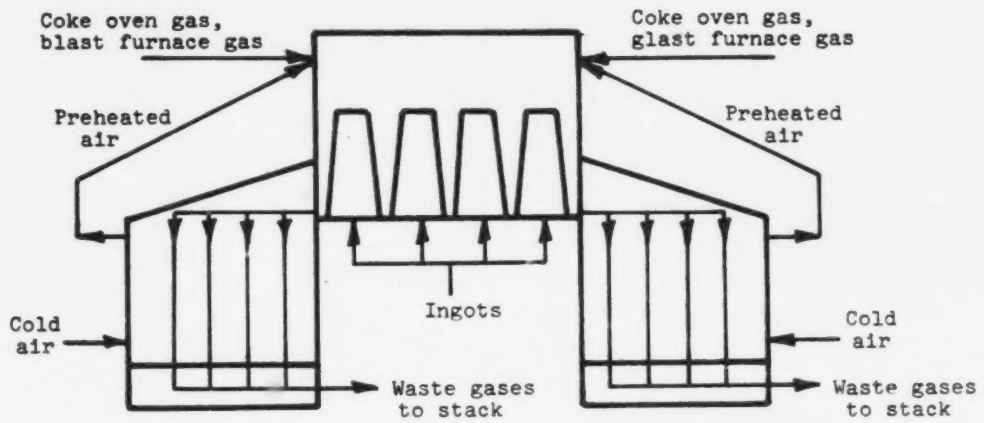
B. Aluminum by the Bayer-Hall Process

Figure 12 shows the principal steps in the Bayer-Hall aluminum manufacturing process. The major energy consumption operations are the steam digestion of bauxite, the evaporation of water from used caustic solution, the calcining of aluminum trihydrate, and the remelting and heat treating of aluminum. These operations account for over 90 percent of the total energy consumption in the aluminum manufacturing process.

Figure 13 shows the steam digestion of bauxite and evaporation of water from caustic. The alumina in bauxite is dissolved in caustic at elevated temperature and pressure. Iron oxide, titania, and silicates do not dissolve but form a red mud which is later separated from the sodium aluminate solution. Later in the process, steam is used to boil water from a dilute caustic solution. Aluminum trihydrate has previously been filtered out of the caustic solution. A set of multi-effect evaporators are used to boil water from the caustic.

Figure 14 shows the use of a rotary kiln to calcine aluminum trihydrate to alumina. The combustion of natural gas in

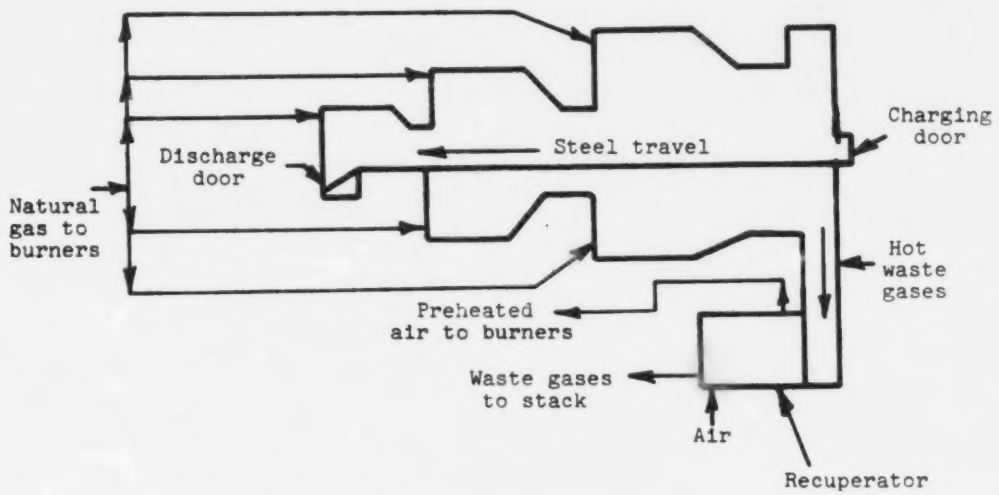
Figure 9. Steel energy intensive equipment diagram - soaking pit
[Rejected heat: Radiation, convection - 460 kJ/kg (200 Btu/lb)
Stack gases - 700 kJ/kg (300 Btu/lb) at 925°K (1200°F)]



Two-way fired soaking pit

Note: All energy is expressed in terms of energy per unit weight of finished steel.

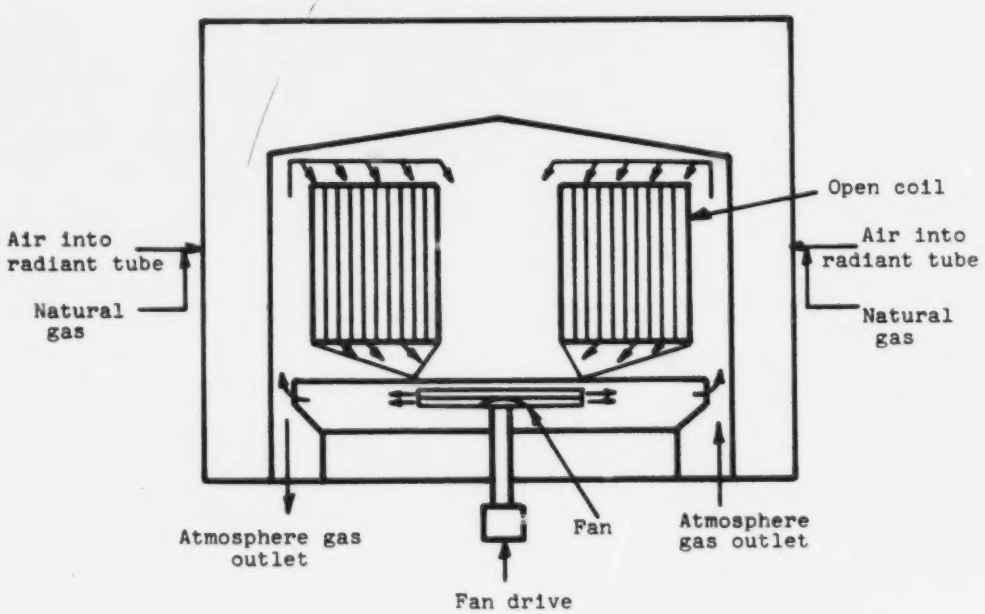
Figure 10. Steel energy intensive equipment diagram - reheating furnace (counter-current pusher-type continuous)
[Rejected heat: Radiation convection - 700 kJ/kg (300 Btu/lb)
Stack gases - 1620 kJ/kg (700 Btu/lb) at 925°K (1200°F)]



Reheating furnace

Note: All energy is expressed in terms of energy per unit weight of finished steel.

Figure 11. Steel energy intensive equipment diagram - annealing ovens
[Rejected heat*: Radiation, conduction, other - 230 kJ/kg (100 Btu/lb)
Exhaust combustion gases: 580 kJ/kg (250 Btu/lb) at 870-1470°K (1100-2200°F)]



Annealing furnace for coiled strip

* Includes annealing and forging oven energy.

Note: All energy is expressed in terms of energy per unit weight of finished steel.

Table 1. STEEL ENERGY CONSERVATION APPROACHES

Causes of energy losses	Approximate magnitude of losses	Energy conservation approaches
1. Coke ovens		
a. Radiation and convection	230 kJ/kg (100 Btu/lb)	Insulation Maintenance
b. Partial non-recovery of sensible heat of flue gases	700 kJ/kg (300 Btu/lb)	Design modification (waste heat recovery)
c. Nonrecovery of sensible heat of coke	720 kJ/kg (310 Btu/lb)	Design modification (dry quench with heat recovery)
d. Nonrecovery of heat in by-products stream	230 kJ/kg (100 Btu/lb)	--
e. Nonrecovery of sensible heat of coke oven gas	460 kJ/kg (200 Btu/lb)	--
f. Wastage of coke oven gas	100 kJ/kg (40 Btu/lb)	Waste utilization
2. Agglomeration		
a. Radiation and convection	230 kJ/kg (100 Btu/lb)	--
b. Exhausting of hot gases from sintering or pelletizing machines and from coolers	1160 kJ/kg (500 Btu/lb)	Design modification (waste heat recovery)
c. Heat in product sinter and pellets	230 kJ/kg (100 Btu/lb)	Design modification (feed hot sinter and pellets to blast furnace)
3. Blast furnace		
a. Radiation, convection, other	1150 kJ/kg (500 Btu/lb)	Insulation Maintenance

Table 1 (continued). STEEL ENERGY CONSERVATION APPROACHES

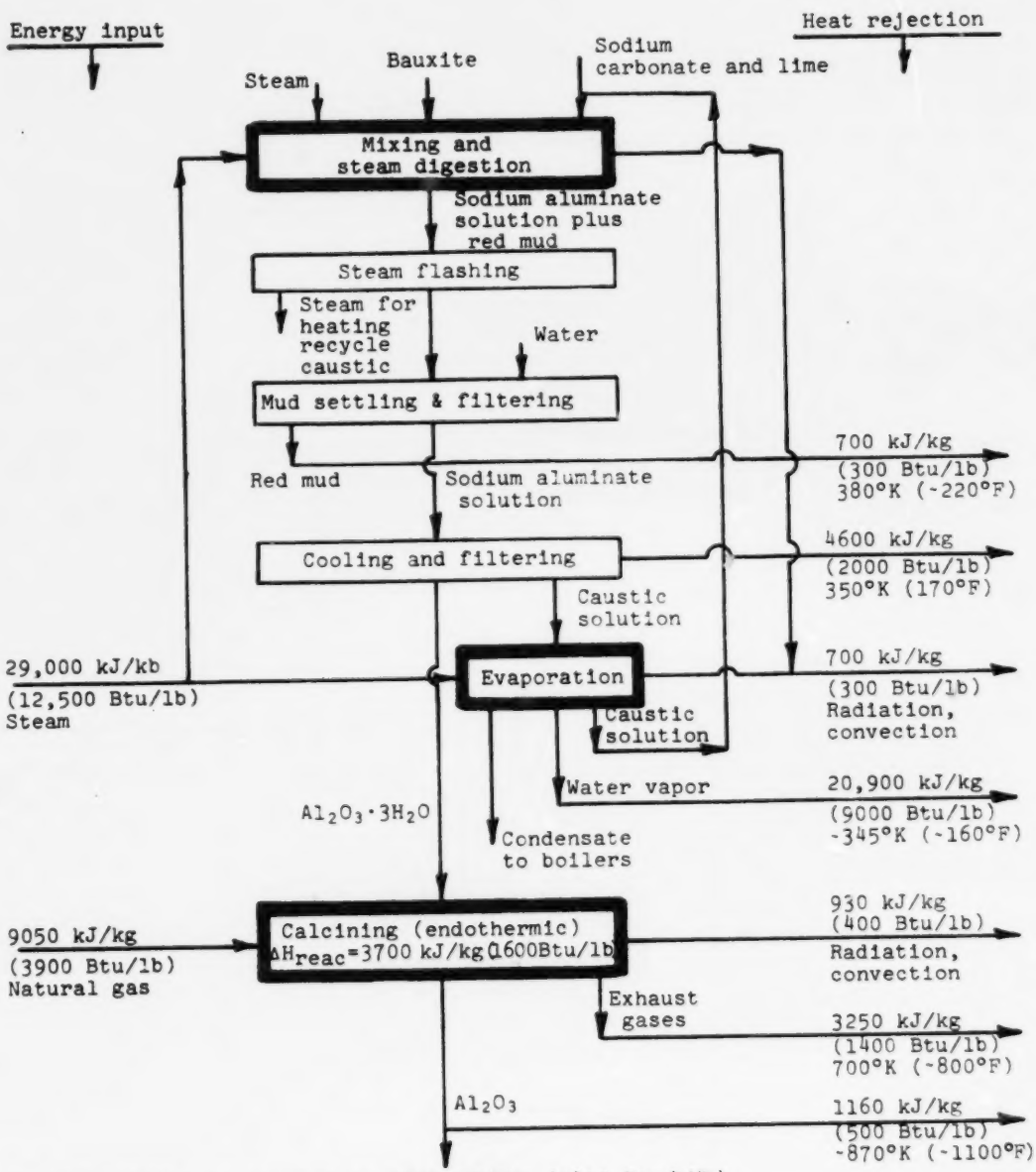
Causes of energy losses	Approximate magnitude of losses	Energy conservation approaches
b. Partial non-recovery of sensible heat of blast furnace gas	700 kJ/kg (300 Btu/lb)	Design modification (waste heat recovery)
c. Nonrecovery of sensible heat of slag	580 kJ/kg (250 Btu/lb)	--
d. Wastage of blast furnace gas	3000 kJ/kg (1300 Btu/lb)	Waste utilization
4. Steelmaking furnace (basic oxygen)		
a. Radiation and convection	115 kJ/kg (50 Btu/lb)	Insulation Maintenance
b. Sensible heat in top gases	580 kJ/kg (250 Btu/lb)	Design modification (waste heat recovery)
5. Soaking pit		
a. Partial non-recovery of sensible heat of combustion gases	700 kJ/kg (300 Btu/lb)	Design modification (waste heat recovery)
b. Radiation and convection, other	460 kJ/kg (200 Btu/lb)	Insulation Maintenance
6. Reheating furnace		
a. Partial non-recovery of sensible heat of combustion bases	1620 kJ/kg (700 Btu/lb)	Design modification (waste heat recovery)
b. Radiation and convection, other	700 kJ/kg (300 Btu/lb)	Insulation Maintenance

Table 1 (continued). STEEL ENERGY CONSERVATION APPROACHES

Causes of energy losses	Approximate magnitude of losses	Energy conservation approaches
7. Annealing or forging furnace		
a. Partial non-recovery of sensible heat of combustion gases	580 kJ/kg (250 Btu/lb)	Design modification (waste heat recovery)
b. Radiation and convection	230 kJ/kg (100 Btu/lb)	Insulation Maintenance
8. Overall process		
a. Higher energy requirement for sintering as compared to pelletizing	460 kJ/kg (200 Btu/lb)	Process modification (increase use of pellets)
b. Higher energy requirement for open hearth furnace	700 kJ/kg (300 Btu/lb)	Process modification (replace open hearth with basic oxygen furnace
c. Formation of scrap throughout the process	2090 kJ/kg (900 Btu/lb)	Process modification (increase use of continuous casting)
d. Loss of sensible heat of ingots between casting and soaking	1700 kJ/kg (730 Btu/lb)	Process modification (use continuous casting)

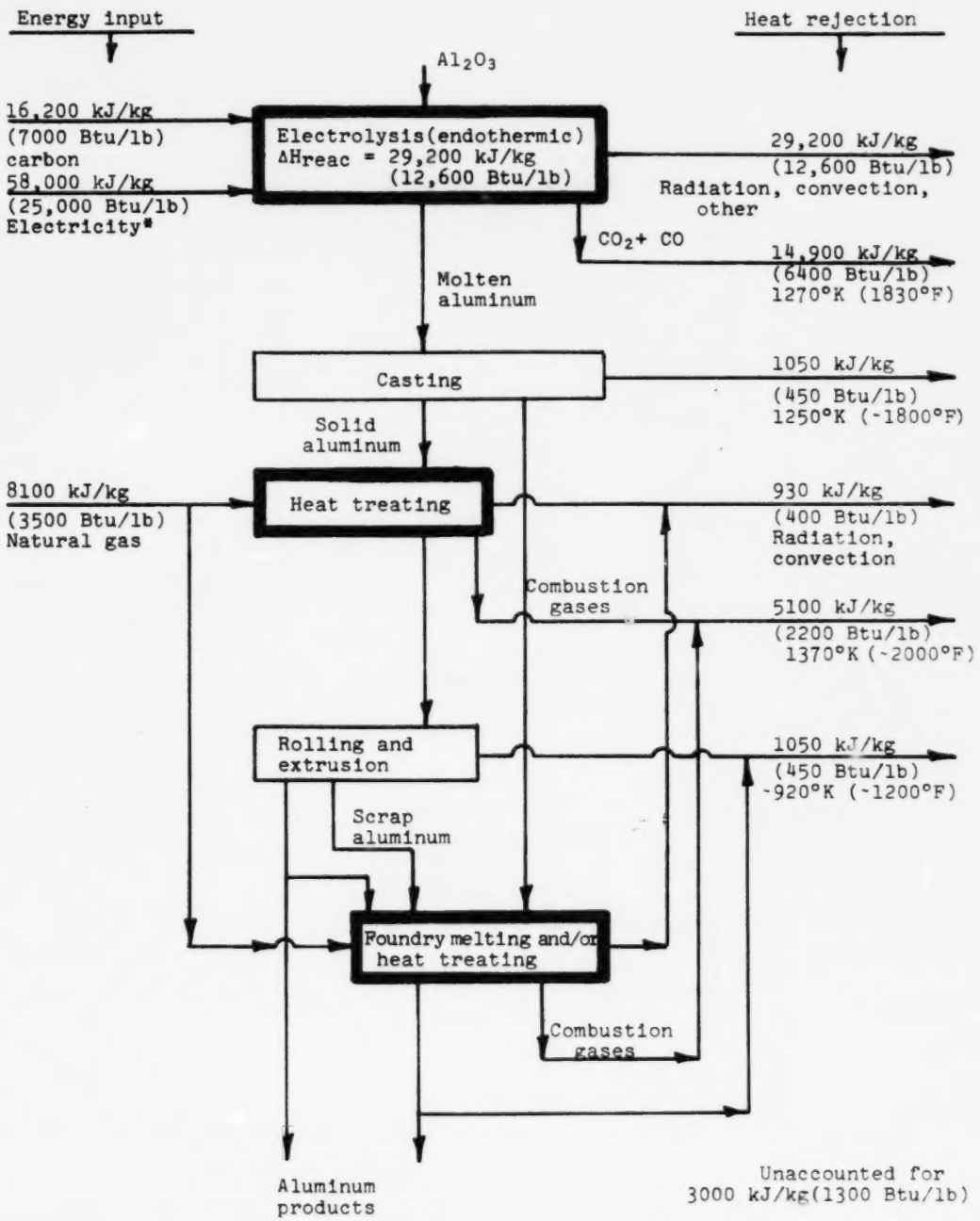
NOTE: All energy values in this table are expressed in terms of energy per unit weight of finished steel.

Figure 12. Aluminum energy consumption diagram
[1972 USA production: 3.74×10^9 kg (8.24×10^9 lb)]
[1972 energy consumption (electricity, carbon, natural gas): 15,000 MW (450×10^{12} Btu)]*



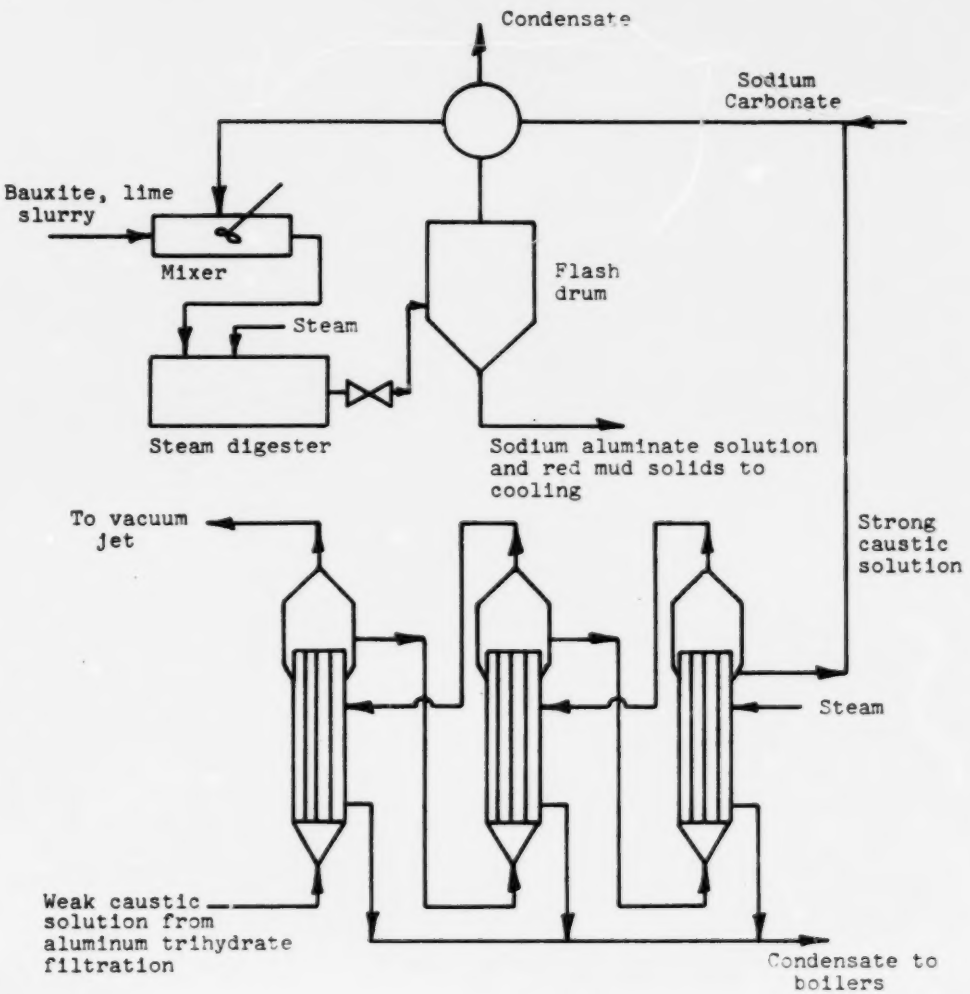
* Electricity is counted as 3600 kJ/kWh (3413 Btu/kWh).
(continued on next page)

Figure 12 (continued)



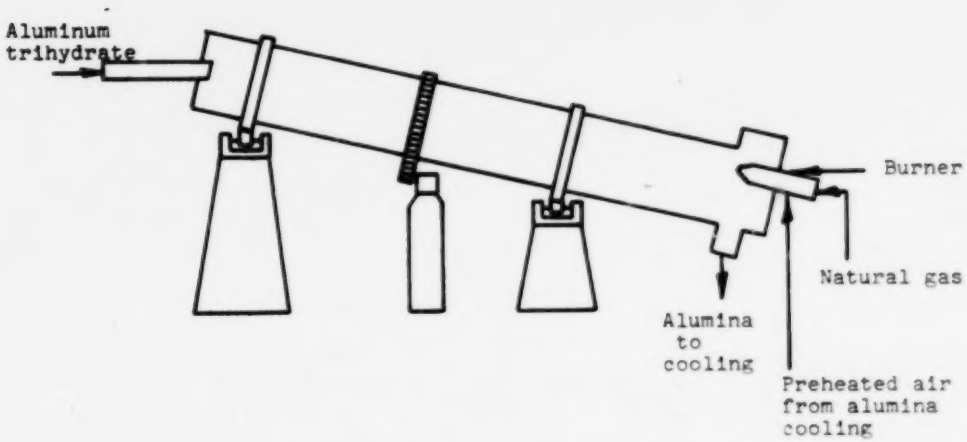
* Electricity is counted as 3600 kJ/kWh (3413 Btu/kWh)

Figure 13. Aluminum energy intensive equipment diagram - steam digestion of bauxite and evaporation of water from caustic
[Rejected heat: Radiation, convection - 700 kJ/kg (300 Btu/lb)
Heat in red mud - 700 kJ/kg (300 Btu/lb) at 380°K (220°F)
Heat in water vapor from evaporators - 20,900 kJ/kg (9000 Btu/lb) at 345°K (160°F)
Heat in sodium aluminate solution - 4600 kJ/kg (2000 Btu/lb) at 350°K (170°F)]



Multi-effect evaporators

Figure 14. Aluminum energy intensive equipment diagram - rotary kiln
[Rejected heat: Radiation - 930 kJ/kg (400 Btu/lb)
Combustion gases - 3250 kJ/kg (1400 Btu/lb) at 700°K (800°F)
Heat in alumina - 1160 kJ/kg (500 Btu/lb) at 870°K (1100°F)]



Rotary kiln

preheated air provides heat to remove water of hydration at 1370°K (2000°F).

Figure 15 shows the electrolytic separation of alumina into aluminum and oxygen (which then reacts with carbon to form carbon dioxide or carbon monoxide). Electricity supplies energy to keep the molten salt bath and molten aluminum at 1250°K (1790°F). Electricity and carbon oxidation also provide energy to dissociate the alumina.

Figure 16 shows the melting of aluminum in a crucible furnace. Approximately one-third of aluminum castings are remelted to obtain finished products. Natural gas is burned to provide heat for melting and for heat treating.

Table 2 lists causes of energy losses in the aluminum manufacturing process. It also gives estimates of energy losses and possible conservation approaches.

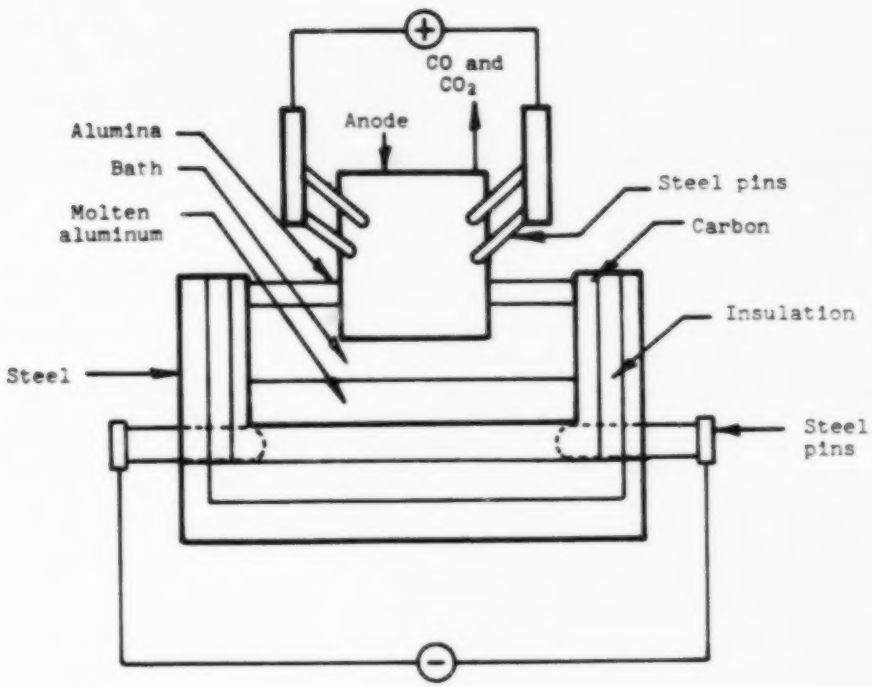
C. Petroleum Refining

Figure 17 shows a petroleum refining process. Refineries vary quite widely in complexity and in product mix. The process shown is representative of a refinery that is producing a high yield of gasoline from crude oil. The primary energy consumption operations include crude oil distillation, gas oil desulfurization, heavy naphtha desulfurization, naphtha desulfurization, catalytic cracking, naphtha reforming, alkylation, aromatics extraction, and coking. Sources of energy for these operations are primarily natural gas, refinery produced gas, petroleum coke, and fuel oil. These operations account for more than 80 percent of the energy consumed in the petroleum refining process shown.

Figure 18 shows the distillation of crude oil. The degree of separation of the crude into components varies from one refinery to another. The scheme shown is fairly elaborate. The principal energy conservation practice is to preheat the crude oil by heat exchange with components leaving the distillation columns. Natural gas or refinery produced gas is burned to supply heat to the column feeds. Steam is also used to provide heat to the strippers and the atmospheric column.

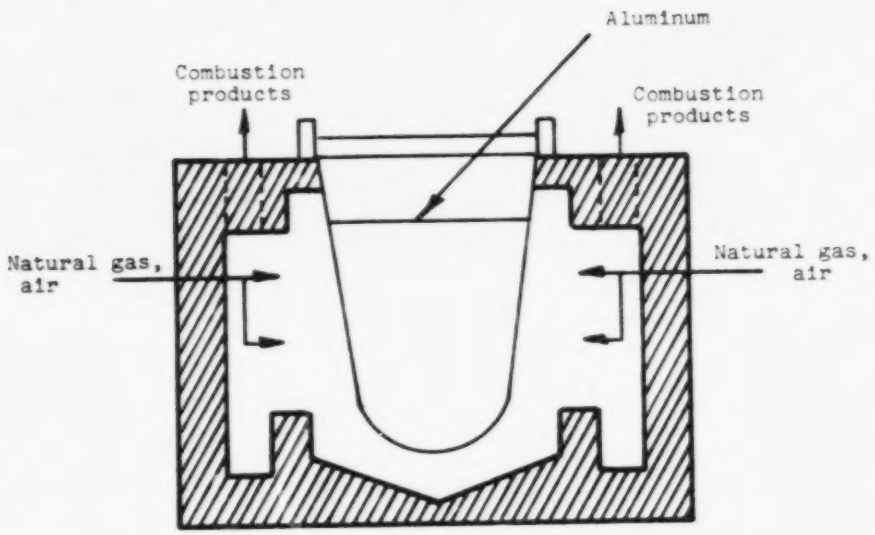
Figure 19 shows the catalytic hydrogenation at high pressure [1350-6800 kN/m^2(200-1000 psi)] of gas oil or naphtha to remove sulfur. The feed is mixed with hydrogen-rich gas, heated to 585-730°K (600-850°F), and passed through a reactor containing a fixed bed of desulfurization catalyst. The feed is heated by hot reactor effluent and by the burning of

Figure 15. Aluminum energy intensive equipment diagram - electrolytic cell
[Rejectei heat: Radiation, convection, other - 29,200 kJ/kg (12,600 Btu/lb)
Exit gases - 14,900 kJ/kg (6400 Btu/lb) at 1270°K (1830°F)]



Alumina electrolysis cell

Figure 16. Aluminum energy intensive equipment diagram - melting furnace
[Rejected heat*: Radiation, other - 930 kJ/kg (400 Btu/lb)
Combustion gases - 5100 kJ/kg (2200 Btu/lb) at -1370°K(-2000°F)
Heat in products - 1050 kJ/kg (450 Btu/lb) at -920°K (-1200°F)]



Crucible furnace

* Heat quantities include melting and heat treating operations.

Table 2. ALUMINUM ENERGY CONSERVATION APPROACHES

Causes of energy losses	Approximate magnitude of losses	Energy conservation approaches
1. Digestion of bauxite & evaporation of water from caustic		
a. Radiation & convection	700 kJ/kg (300 Btu/lb)	Insulation Maintenance
b. Heat in red mud	700 kJ/kg (300 Btu/lb)	
c. Heat removed in cooling of aluminate solution	4600 kJ/kg (2000 Btu/lb)	
d. Heat in vapor leaving evaporators	20,900 kJ/kg (9000 Btu/lb)	Design modification (optimize evaporation scheme) Operation modification (close control of wash water volume)
2. Calcining		
a. Heat in exit combustion gases	3250 kJ/kg (1400 Btu/lb)	Operation modification (control of air/fuel ratio). Design modification (more complete heat recuperation)
b. Radiation and convection	930 kJ/kg (400 Btu/lb)	Insulation Maintenance
c. Heat in alumina	1160 kJ/kg (500 Btu/lb)	Operation modification (feed hot alumina to cells). Design modification (more complete heat recuperation
3. Electrolytic reduction		
a. Anode overvoltage, resistance and electrical connection	4650 kJ/kg (2000 Btu/lb)	Operation modification (lower current density). Research and development (catalytic additive to anode)

Table 2. (continued). ALUMINUM ENERGY CONSERVATION APPROACHES

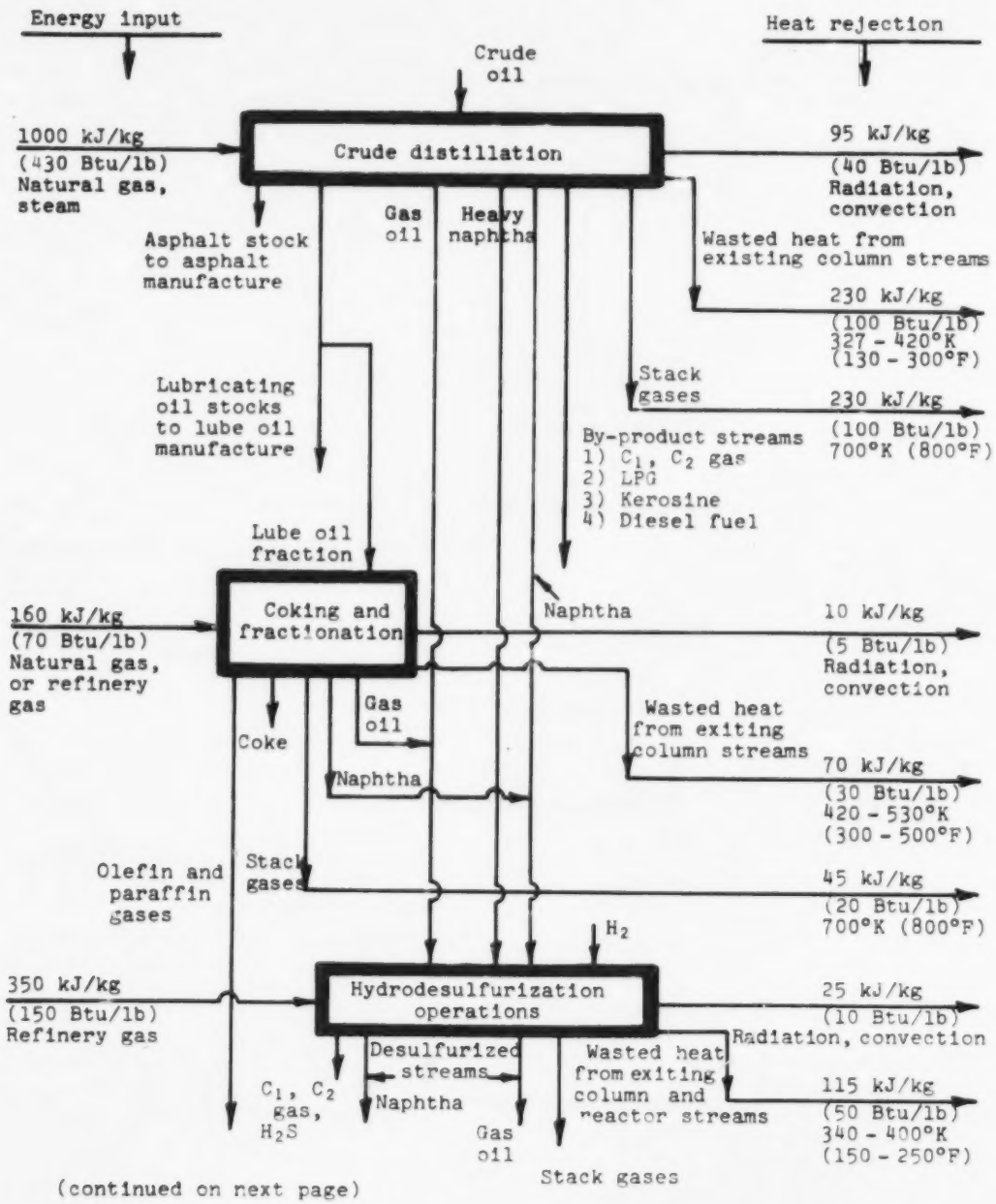
Causes of energy losses	Approximate magnitude of losses	Energy conservation approaches
b. Cathode resistance	4650 kJ/kg (2000 Btu/lb)	Operation modification (lower current density). Research and development (alternative cathode materials)
c. Electrolyte resistance	20,400 kJ/kg (8800 Btu/lb)	Design modification (closer anode-cathode spacing). Operation modification (lower current density)
d. Resistance between cells	1850 kJ/kg (800 Btu/lb)	Operation modification (lower current density). Design modification
e. Recombination of aluminum with oxygen	8100 kJ/kg (3500 Btu/lb)	Operation modification (closer control of cell operation)
f. Excess carbon consumption	5350 kJ/kg (2300 Btu/lb)	- - - - - - - -
4. Remelting and heat treating		
a. Heat in combustion gases	5100 kJ/kg (2200 Btu/lb)	Design modification (waste heat recovery)
b. Radiation and convection	930 kJ/kg (400 Btu/lb)	Insulation Maintenance
5. Overall process losses		
a. Lack of aluminum recycling	32,000 kJ/kg (14,000 Btu/lb)	Waste utilization (more aluminum recycling).
b. Higher energy requirement of Hall process as compared to new Alcoa process	25,000 kJ/kg (11,000 Btu/lb)	Process modification (replacement of Hall process with new Alcoa process)

Table 2 (continued). ALUMINUM ENERGY CONSERVATION APPROACHES

Causes of energy losses	Approximate magnitude of losses	Energy conservation approaches
c. Radiation convection from electrolysis cell	29,200 kJ/kg (12,600 Btu/lb)	Insulation
d. Heat in exit gases from electrolysis cell	14,900 kJ/kg (6400 Btu/lb)	Design modification (waste heat recovery)

NOTE: Electrolytic reduction losses are electrical. Overall process losses a. and b. are primarily electrical. The fuel equivalent for these losses would be approximately three times the listed values.

Figure 17. Petroleum refining energy consumption diagram
[1971 USA production: 610 x 10^9 kg (1350 x 10^9 lb)]
[1971 energy consumption (primarily natural gas, refinery gas, petroleum coke, fuel oil) 94,000 MW (2.8 x 10^{15} Btu)]



(continued on next page)

Figure 17 (Continued).

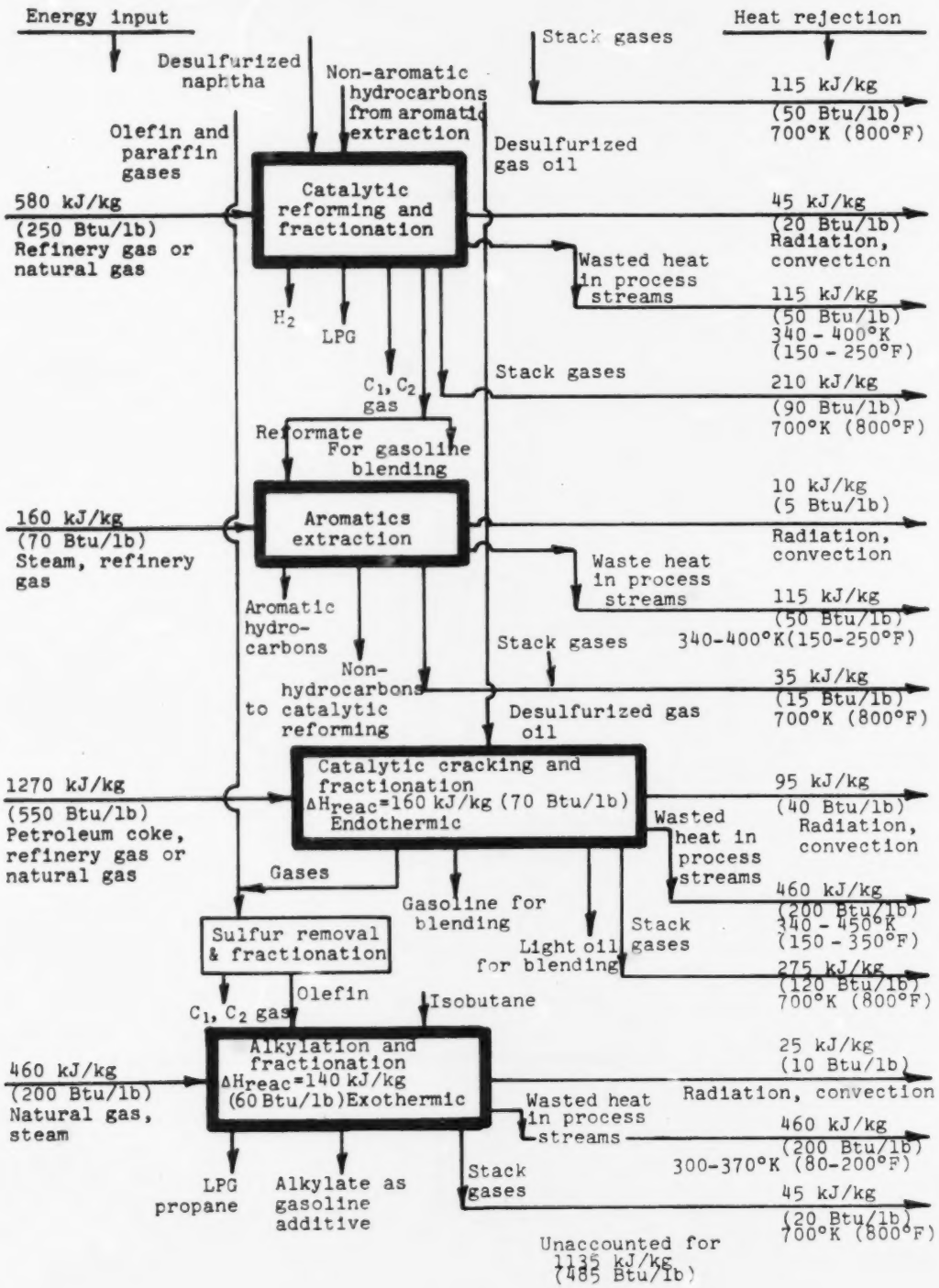


Figure 18. Petroleum refining energy intensive equipment diagram - crude distillation
[Rejected heat: Radiation - 95 kJ/kg (40 Btu/lb)
Heater stack gases - 230 kJ/kg (100 Btu/lb) at 640°K (700°F)
Hot exiting column steams (wasted) - 230 kJ/kg (100 Btu/lb) at 327 - 420°K (130 - 300°F)]

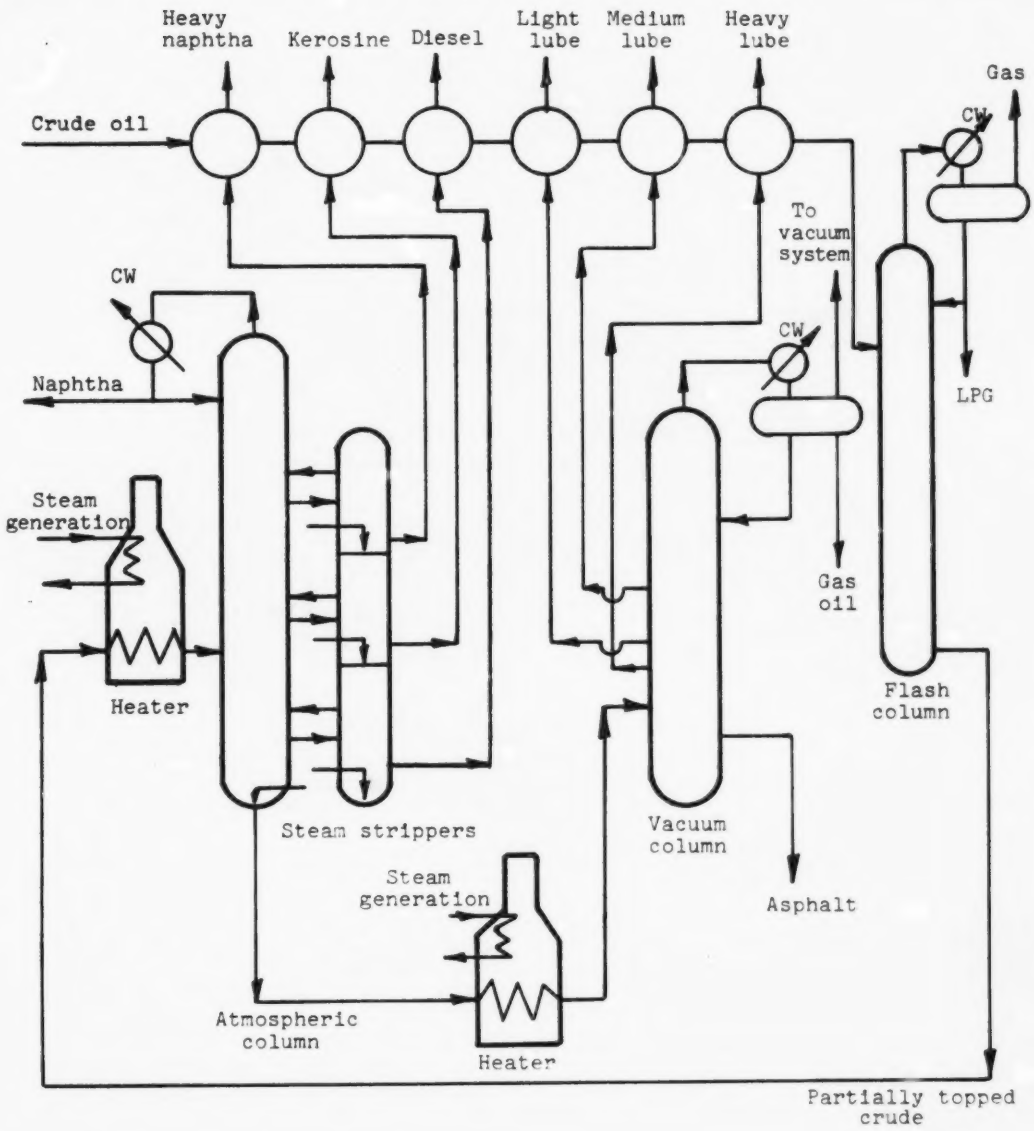
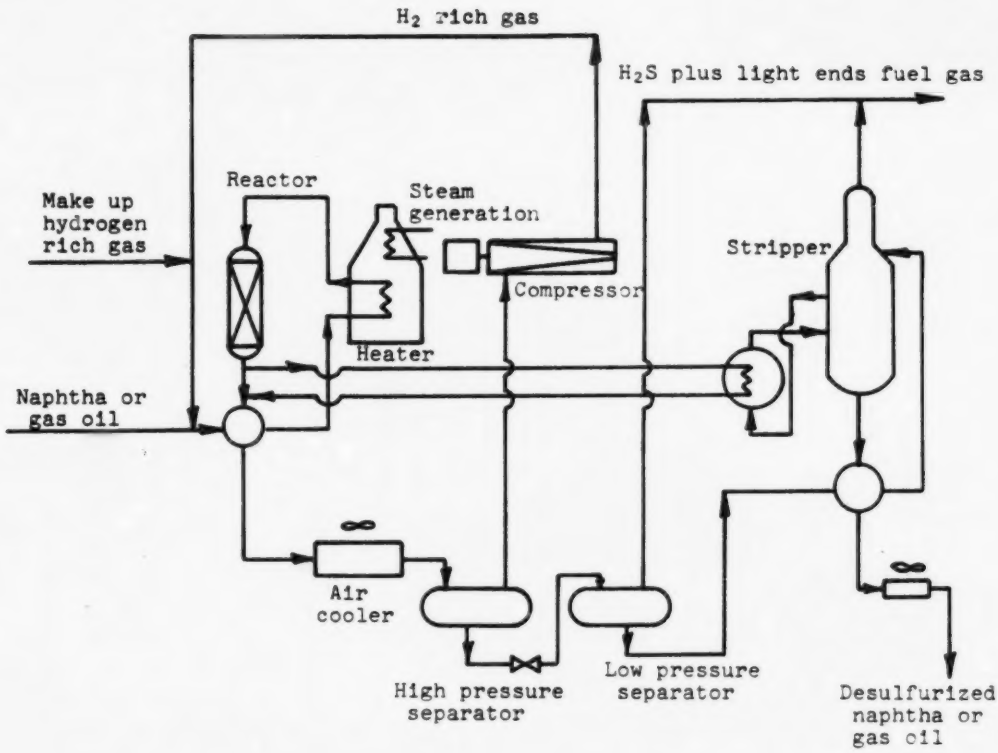


Figure 19. Petroleum refining energy intensive equipment diagram - distillate hydrodesulfurization
[Rejected heat: Radiation, convection - 25 kJ/kg (10 Btu/lb)
Heater stack gases - 115 kJ/kg (50 Btu/lb) at 700°K (800°F)
Wasted heat in process streams - 115 kJ/kg (50 Btu/lb) at 340 - 400°K (150 - 250°F)]



natural gas or refinery-produced gas in a heater. The product is separated from gases in a high pressure separator, low pressure separator, and a stripper. Heat to the stripper is supplied by hot reactor effluent.

Figure 20 shows the catalytic reforming operation where naphthas are converted to aromatic hydrocarbons. The dehydrogenation reactions take place at high pressure [2000-4000 kN/m^2(300-600 psi)] and at elevated temperatures [720-810°K (840-1000°F)] in a hydrogen atmosphere. Natural gas or refinery-produced gas is burned in heaters to provide heat for the endothermic reactions which occur. Hot reactor effluent is used to preheat incoming feed and to provide heat to the fractionator at the end of this operation.

Figure 21 shows a fluid catalytic cracking operation. Gas oil is preheated in a natural gas or refinery-produced gas-fired heater. It then carries regenerated catalyst into the reactor-settler. The product comes out of the top of the reactor while spent catalyst overflows a weir and falls through a steam stripper. The steam removes entrained hydrocarbons. Then the spent catalyst goes to the catalyst regenerator where coke is burned off the catalyst. Regenerated catalyst then flows to the gas oil feed to be swept into the reactor. The product from the reactor is fed to a fractionator where gas, gasoline, and light oil are obtained. The temperatures in this operation are approximately 740°K (870°F) in the reactor and 900°K (1160°F) in the catalyst regenerator. Coke combustion in the catalyst regenerator supplies heat for the reactions which occur in the reactor. The flue gas from the regenerator contains combustible carbon monoxide fuel.

Figure 22 shows an alkylation operation where isobutane reacts with a C_3 to C_5 olefin stream in the presence of a catalyst. The products are branch-chained C_5 to C_{10} hydrocarbons with a high octane number. The product is called the alkylate and is blended into gasoline. The reaction takes place at low temperature [285-320°K (50-110°F)] and is exothermic. The reactor products are separated by distillation. The fractionator is heated by burning natural gas or refinery-produced gas in the reboiler furnace.

Figure 23 shows an aromatic extraction operation in which reformed naphtha is separated into its aromatic and non-aromatic components. A glycol-water mixture flows into an extractor and dissolves the aromatic portion of the reformed naphtha feed. The rich solvent is then taken to a stripper where the dissolved aromatics are separated from the solvent. The aromatics then go to a water wash tower where traces of

Figure 20. Petroleum refining energy intensive equipment diagram - catalytic reforming
[Rejected heat: Radiation, convection - 45 kJ/kg (20 Btu/lb)
Furnace stack gases - 210 kJ/kg (90 Btu/lb) at 700°K (800°F)
Wasted heat in process streams - 115 kJ/kg (50 Btu/lb) at 340 - 400°K (150 - 250°F)]

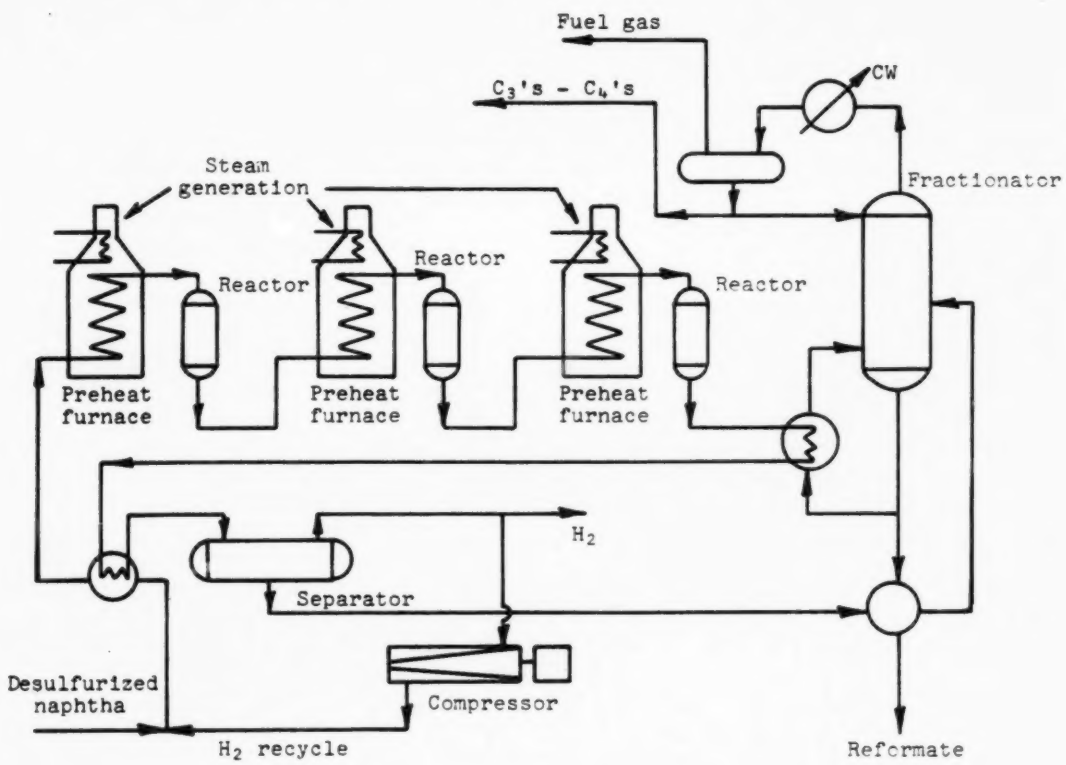


Figure 21. Petroleum refining energy intensive equipment diagram - fluid catalytic cracking
[Rejected heat: Radiation, convection - 95 kJ/kg (40 Btu/lb)
Furnace stack gases: 115 kJ/kg (50 Btu/lb) at 700°K (800°F)
Wasted heat in process streams: 460 kJ/kg (200 Btu/lb) at 340 - 450°K (150 - 350°F)
Reactor stack gases: 160 kJ/kg (70 Btu/lb) at 700°K (800°F)]

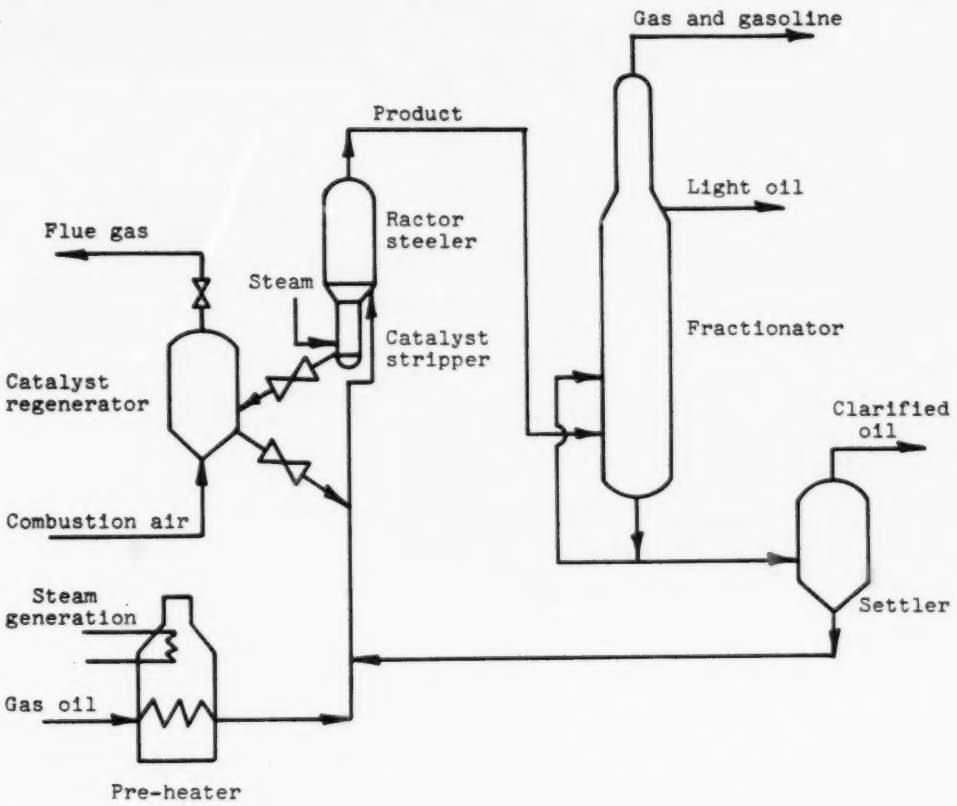


Figure 22. Petroleum refining energy intensive equipment diagram - HF alkylation
[Rejected heat: Radiation, convection - 25 kJ/kg (10 Btu/lb)
Furnace stack gases - 45 kJ/kg (20 Btu/lb) at 700°K (800°F)
Wasted heat in process streams - 460 kJ/kg (200 Btu/lb)
at 300 - 370°K (80 - 200°F)]

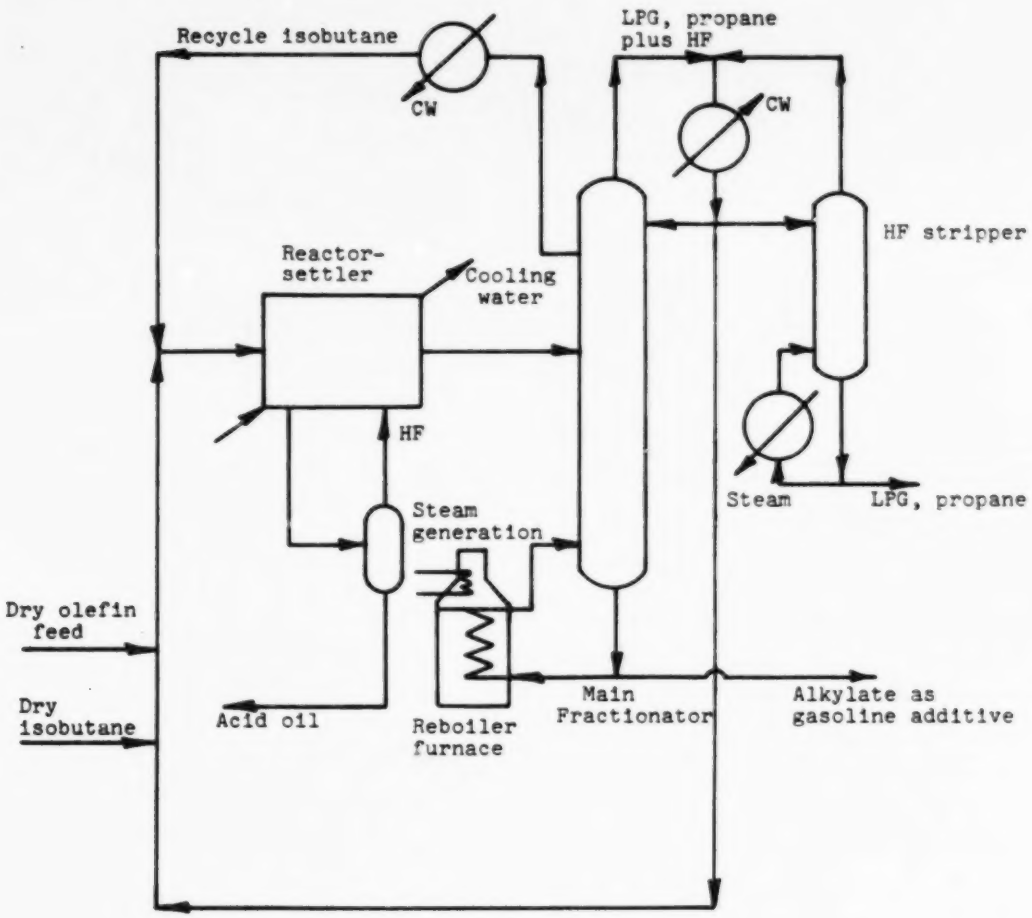
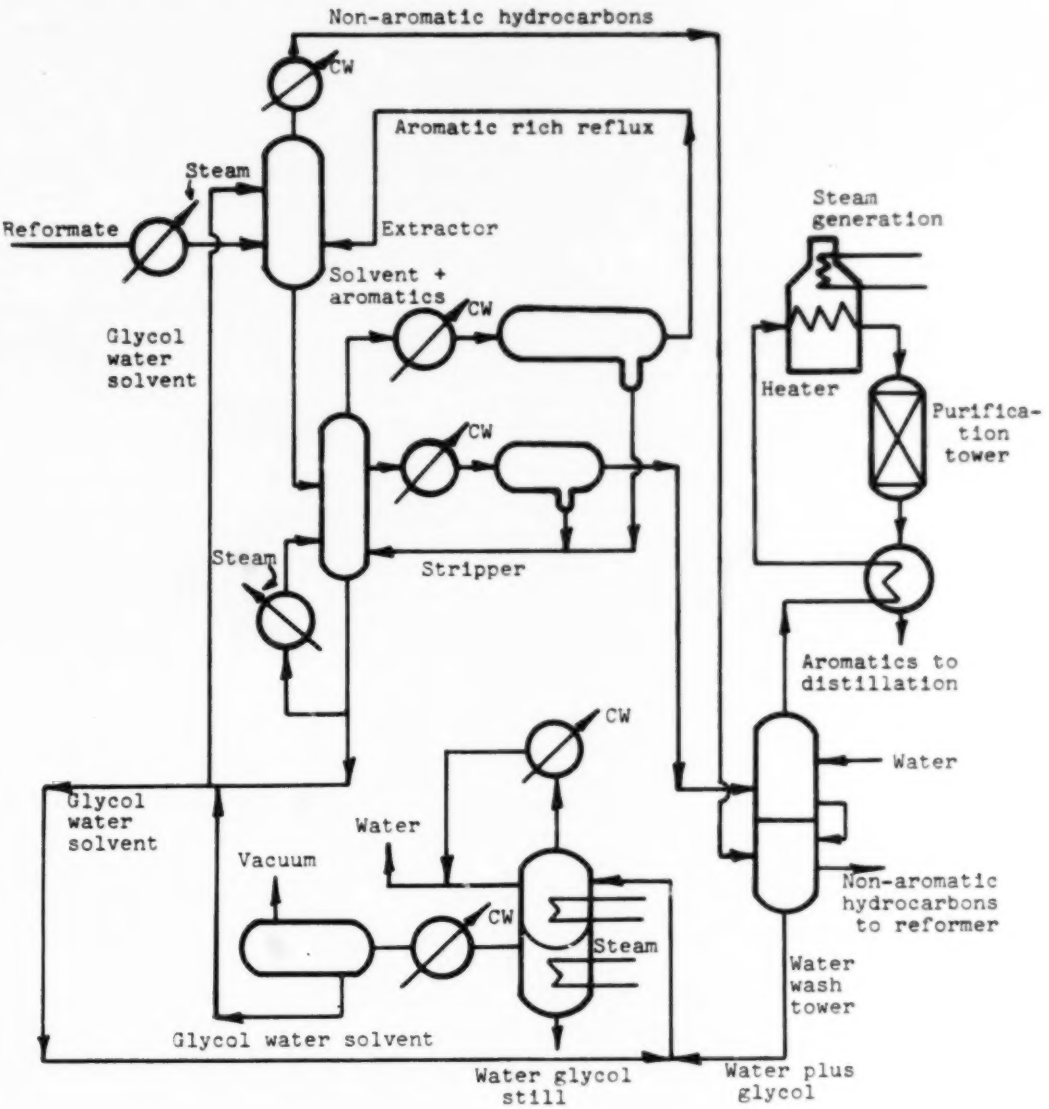


Figure 23. Petroleum refining energy intensive equipment diagram - aromatics extraction
[Rejected heat: Radiation, convection - 10 kJ/kg (5 Btu/lb)
Furnace stack gases - 35 kJ/kg (15 Btu/lb) at 700°K (800°F)
Wasted heat in process streams - 115 kJ/kg (50 Btu/lb) at 340 - 400°K (150 - 250°F)]



dissolved glycol are removed. The aromatics then are heated in a natural gas or refinery gas-fired heater and fed to a clay tower where impurities are removed. Steam is used to provide heat to the water glycol still shown in the figure.

Figure 24 shows a cking operation where heavy residuals are upgraded into more valuable distillate products and coke. The residue is fed to a distillation column where light gases are flashed. The remaining material combines with recycle and is pumped to a natural gas or refinery-produced gas-fired heater where it is heated to 770°K (920°F). The liquid-vapor mixture leaving the heater passes to a coking drum. Coke builds up to a predetermined level in one drum, and then flow is diverted to the next drum. The full drum is steamed to strip out unconverted hydrocarbons, cooled by water, and then is hydraulically decoked with high pressure water jets. The coke drum overhead vapor goes to the distillation column for separation into gas, gasoline, and gas oil.

Table 3 shows the causes of energy losses in the petroleum refining process. It also gives estimates of the losses and possible conservation approaches.

D. Summary of Energy Losses and Recommended Conservation Approaches

Table 4 is a summary of energy losses and recommended conservation approaches for the steel, aluminum, and petroleum industries. Combustion is the dominant operation in the steel and petroleum refining processes while electrolysis is the dominant operation in the aluminum process. Opportunities are available for energy conservation in both of these operations.

Figure 24. Petroleum refining energy intensive equipment diagram - coking
[Rejected heat: Radiation, convection - 10 kJ/kg (5 Btu/lb)
Furnace stack gases - 45 kJ/kg (20 Btu/lb) at 700°K (800°F)
Hot exiting column streams (wasted) - 70 kJ/kg (30 Btu/lb)
at 420 - 530°K (300 - 500°F)]

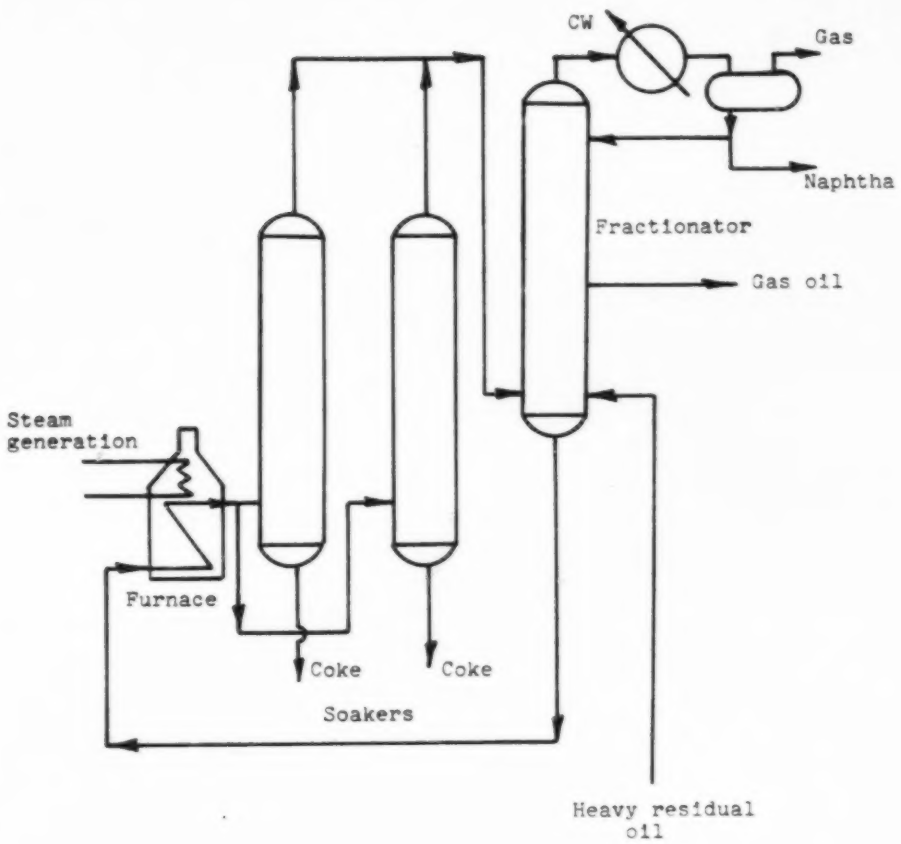


Table 3. PETROLEUM REFINING ENERGY CONSERVATION APPROACHES

Causes of energy losses	Approximate magnitude of losses	Energy conservation approaches
1. Rejected heat		
a. Unrecovered heat in streams exiting energy intensive operations	1560 kJ/kg (680 Btu/lb)	Design modification (optimize heat exchange system) Maintenance (keep heat exchange surfaces clean)
b. Unrecovered heat in stack gases	955 kJ/kg (415 Btu/lb)	Design modification (waste heat recovery)
c. Radiation, convection	305 kJ/kg (130 Btu/lb)	Insulation Maintenance
d. Unaccounted for	1135 kJ/kg (485 Btu/lb)	--
2. Overall process		
a. High reflux ratios in distillation columns	115 kJ/kg (50 Btu/lb)	Design modification (more plates in column). Operation modification (closer control of columns)
b. Unrecovered potential energy (pressure) in several operations	70 kJ/kg (30 Btu/lb)	Design modification (use hydraulic and expander turbines)
c. Loss of fuel value of flue gas from catalytic cracking regenerator	115 kJ/kg (50 Btu/lb)	Waste utilization (use as fuel in boiler)
d. Lack of integration of electrical generation with steam generation	460 kJ/kg (200 Btu/lb)	Process integration

Table 4. SUMMARY OF ENERGY LOSSES AND RECOMMENDED CONSERVATION APPROACHES

Industry	High energy consumption operations	Level and approximate magnitude of losses (Temperature level)	(Approximate magnitude of losses)	Energy conservation approaches
Steel	Combustion, heating and cooling	Radiation, convection 350-500°K (170-440°F) 500-600°K (440-620°F) 600-700°K (620-800°F) 700-1000°K (800-1340°F) 1000-1500°K (1340-2240°F) 1500-2100°K (2240-3320°F)	3115 kJ/kg (1350 Btu/lb) 1390 kJ/kg (600 Btu/lb) 230 kJ/kg (100 Btu/lb) 1400 kJ/kg (600 Btu/lb) 3010 kJ/kg (1300 Btu/lb) 1650 kJ/kg (710 Btu/lb) 4180 kJ/kg (1810 Btu/lb)	1. Design modification 2. Insulation 3. Maintenance 4. Waste utilization
	Overall process	--	--	Process modification
Aluminum	Electrolysis	Radiation, convection 1270°K (1830°F)	29,200 kJ/kg (12,600 Btu/lb) 14,900 kJ/kg (6400 Btu/lb)	1. Operation modification 2. Research & development 3. Design modification
	Digestion & evaporation	Radiation, convection 345°K (160°F)	700 kJ/kg (300 Btu/lb) 20,900 kJ/kg (9000 Btu/lb)	1. Design modification 2. Operation modification 3. Insulation
	Kiln	Radiation, convection 700°K (800°F) 870°K (1100°F)	930 kJ/kg (400 Btu/lb) 3250 kJ/kg (1400 Btu/lb) 1160 kJ/kg (500 Btu/lb)	1. Design modification 2. Insulation 3. Operation modification
	Overall process	--	--	1. Waste utilization 2. Process modification

Table 4 (continued). SUMMARY OF ENERGY LOSSES AND RECOMMENDED CONSERVATION APPROACHES

Industry	High energy consumption operations	Level and approximate magnitude of losses (Temperature level)	(Approximate magnitude of losses)	Energy conservation approaches
	Overall process	--	--	3. Insulation 4. Design modification
Petroleum	Combustion and distillation	Radiation, convection 300-550°K (80-530°F) ~700°K (~800°F)	305 kJ/kg (130 Btu/lb) 1570 kJ/kg (680 Btu/lb) 960 kJ/kg (415 Btu/lb)	1. Design modification 2. Insulation 3. Maintenance
	Overall process	--	--	1. Design modification 2. Operation modification 3. Waste utiliation

SECTION V

BIBLIOGRAPHY

Berg, C. A. Conservation in Industry. Science. 184:264-270, April 19, 1974.

Brantley, F. E. Iron and Steel. In: Minerals Yearbook 1972, Schreck, A. E. (ed.). Washington, U. S. Government Printing Office, 1974. 1:427-460.

Bravard, J. C., H. B. Flora, and C. Portal. Energy Expenditures Associated with the Production and Recycle of Metals. Oak Ridge National Laboratory, Oak Ridge, Tennessee. Publication Number ORNL-NSF-EP-24. November 1972. 87 p.

Carney, D. J. Electric Furnace Steelmaking in the Next Decade. Journal of Metals. 26:41-47, March 1974.

Frith, J. F., B. M. Bergen, and M. M. Shreehan. Optimize Heat Train Design. Hydrocarbon Processing. 52:89-91, July 1973.

Gyftopoulos, E. P., Director. Study of Effectiveness of Industrial Fuel Utilization. Thermo Electron Corporation, Waltham, Massachusetts. Report No. TE 5357-71-74. January 1974. 120 p.

Hayden, J. E., and W. H. Levers. Design Plants to Save Energy. Hydrocarbon Processing. 52:72-75, July 1973.

Hobson, G. D., and W. Pohl (ed.). Modern Petroleum Technology, 4th edition. New York, John Wiley & Sons, 1973. 996 p.

Hoffman, H. L. (ed.). 1974 Refining Process Handbook. Hydrocarbon Processing. 53:103-214. September 1974.

Jones, F. A. Build and Run Plants to Save Energy. Hydrocarbon Processing. 53:89-93, July 1974.

Klinger, F. L. Iron Ore. In: Minerals Yearbook 1972, Schreck, A. E. (ed.). Washington, U. S. Government Printing Office, 1974. 1:611-639.

Kobrin, C. L. Steel's Changing Uses of Energy. The Iron Age. 201:145-154, June 6, 1968.

McGannon, H. E. (ed.). The Making, Shaping and Treating of Steel, 9th edition. Pittsburgh, Herbick and Held, 1971. 1420 p.

McManus, G. J. Electric Steelmaking Assumes New Role. Iron Age. 213:45-48;53-56, April 1, 1974.

Nelson, W. L. Petroleum (Refinery Processes). In: Kirk-Othmer Encyclopedia of Chemical Technology, 2nd edition, Standen, A. (ed.). New York, John Wiley and Sons, Inc., 1968. 15:1-77.

Peacey, J. H., and W. G. Davenport. Evaluation of Alternative Methods of Aluminum Production. Journal of Metals. 26:25-28, July 1974.

Reese, K. M., and W. H. Cundiff. Alumina. In: Modern Chemical Processes, Murphy, W. J. (ed.). New York, Reinhold Publishing Company, 1956. 4:180-188.

Reh, L. Fluidized Bed Processing. Chemical Engineering Progress. 67:58-63, February 1971.

Shaw, R. W. The Impact of Energy Shortages on the Iron and Steel Industries. Booz, Allen and Hamilton, Inc., Bethesda, Maryland. Contract No. 14-01-0001-1657. August 1974.

Sheridan, E. T. Coke and Coal Chemicals. In: Minerals Yearbook 1972, Shreck, A. E. (ed.). Washington, U. S. Government Printing Office, 1974. 1:427-460.

A Study of Process Energy Requirements in the Iron and Steel Industry. New York, American Gas Association, Inc. 69 p.

A Study of Process Energy Requirements in the Petroleum Industry. New York, American Gas Association, Inc. 82 p.

Trinks, W., and M. H. Mawhinney. Industrial Furnaces, 5th edition, volume 1. New York, John Wiley and Sons, Inc., 1961. 486 p.

Trinks, W., and M. H. Mawhinney. Industrial Furnaces, 4th edition, volume 2. New York, John Wiley and Sons, Inc., 1967. 358 p.

Vachet, P. Aluminum and Aluminum Alloys. In: Kirk-Othmer Encyclopedia of Chemical Technology, 2nd edition, Standen, A. (ed.). New York, John Wiley and Sons, Inc., 1963. 1:937-946.

Whitcomb, M. G., and F. M. Orr. Plan Plant Energy Conservation. Hydrocarbon Processing. 52:65-66, July 1973.

SECTION VI

GLOSSARY OF ABBREVIATIONS

Btu	British thermal unit
cond	condensate
CW	cooling water
kg	kilogram
kJ	kiloJoule
kN	kiloNewton
lb	pound
m	meter
psia	pounds per square inch absolute
MW	megawatt
stm	steam
yr	year

SECTION VII

APPENDIX

ENERGY CONSERVATION APPROACHES

Design modification - This term includes design changes in equipment or process.

Insulation - This term implies that a review of the economics of additional insulation is needed.

Maintenance - This term implies that the economics of additional maintenance effort needs review.

Process integration - This term relates to the best use of steam by using the same steam in more than one process or to the optimization of the steam-electricity production ratio.

Research and development - This term relates to the improvement of processes by future discoveries.

Operation modification - This term includes changes in operating procedures or practices that do not require a design change.

Market modification - This term relates to the substitution of a low energy consumption product for a high energy consumption product.

Process modification - This term relates to a change in a process due to a change in process feedstock, raw materials, or process route.

Waste utilization - This term relates to the use of fuel value of waste process streams or to the recycling of discarded materials.